



ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

An International Review of Eco-City Theory, Indicators, and Case Studies

Nan Zhou and Christopher Williams

China Energy Group

Environmental Energy Technologies Division

Lawrence Berkeley National Laboratory

March 2013

This work was supported by the China Sustainable Energy Program of the Energy Foundation and the Collaborative Labeling & Appliance Standards Program through the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

Disclaimer

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor The Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or The Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof, or The Regents of the University of California.

Ernest Orlando Lawrence Berkeley National Laboratory is an equal opportunity employer.

Acknowledgments

This work has benefited from the input of many colleagues. In particular the author would like to thank Chris Jones and Hazel Onsrud at the University of California, Berkeley California Cool Climate Network; Josh Geyer and Justin Sheid at the U.S. Department of Housing and Urban Development; Eugenie L. Birch, University of Pennsylvania PennDesign Institute; Artessa Saldivar-Sali, World Bank Urban Development and Local Government Unit; and Steve Hammer, Lecturer in Energy Planning, Massachusetts Institute of Technology for their helpful comments and inputs.

An International Review of Eco-City Theory, Indicators, and Case Studies

Nan Zhou and Christopher Williams

China Energy Group

Environmental Energy Technologies Division

Lawrence Berkeley National Laboratory

Executive Summary

This report is intended to answer the question: “What international experiences with ‘eco-cities’ can help the central Chinese government evaluate the performance of Chinese cities that pursue ‘low-carbon’ urban development?” To answer this question, we reviewed the literature on eco-cities and closely related concepts, surveyed performance indicators used to evaluate sustainable urban development around the world, and compiled case studies of exceptional eco- and sustainable cities.

Part I of this report describes our review of urban planning, architecture, urban studies, and civil engineering literature. The goal of this review was to determine how theorists and advocates have used the term “eco-city” and similar concepts throughout the past 150 years and to identify other terms and concepts used to describe eco-cities and characteristic eco-city features.

Part II of this report looks at the performance indicators that governments, institutions, academics, and citizens are using to evaluate the sustainability or “green” performance of urban developments. This section of the report identifies, to the extent possible, themes and indicators that are common among the indices used to evaluate cities.

Part III presents case studies of cities that are viewed internationally as leaders in instituting progressive eco-city policies and technologies.

The central finding of this research is that there is an array of opportunities to combine existing theory to develop a system that the Chinese government can use to evaluate eco-cities, but the definitions and indicators used must be tuned to the Chinese context and specifically to locally defined policy goals, to the extent that local administrations have the power to define these goals.

Our literature review reveals that there no consensus on a definition of eco-city, nor are there scientifically based criteria for evaluating eco-cities. The term “eco-city,” and similar concepts such as “green” and “sustainable” cities, have evolved over time concurrent to the development of the understanding of social change and mankind’s impact on environmental and economic health. The terms “green city,” “sustainable city,” and “eco-city” will likely continue to evolve as best practices for economic sustainability and social health evolve. In addition,

evaluating a city's relationship to and impact on its environment, inhabitants, and the market is complex from a theoretical standpoint and challenging because data on eco-cities vary and cannot be easily compared. In sum, "eco-city" and similar terms are used subjectively. For this concept to usefully inform Chinese policy, eco-city goals that are specific to China should be developed.

The eco-city concept and other similar ideas originated during the late industrial revolution in response to the poor health and living conditions of urban populations at the time. The eco-city idea has evolved, mostly in the United States and Western Europe; we have identified five forms this idea has taken, which have overlapped through time and are often additive to previous forms: 1) integrating an agrarian settlement mode into city-like settlements to increase health and reduce social discord related to poverty; 2) protecting human and local environmental and ecosystem health; 3) protecting global environmental health; 4) integrating broad concepts of social health, such as economic and social equity; and, most recently, 5) incorporating climate change resilience and technological advances. This evolution has produced a diversity of concepts, many of which have been integrated into eco-city theory by proponents despite a lack of consensus on the exact detail of each or the priority of strategies to be pursued. Broadly, an eco-city should incorporate plans, measures, technologies, and operational strategies to increase all aspects of environmental, social, and economic health; narrowly, these goals should be accomplished primarily by efforts to conserve natural resources, reduce fossil fuel use, increase density and reduce automobile use, reduce and recycle waste streams, integrate nature into cities, shift the economy toward the service sector and high-value added technology creation, build diverse spaces that offer value to all population subgroups, and actively seek and support community involvement in city improvement efforts. Although the definition of an eco-city varies, systems of evaluating eco-city performance have, during the past 20 years, moved from reliance on qualitative principles to reliance on quantitative performance metrics.

Because the term "low-carbon eco-city" has only recently attained popularity in China and is not used elsewhere, there are no existing indicator systems to measure the performance of such a city. However, there is some high-level consensus on the types of phenomena that should be measured in evaluating sustainable, green, eco-, and similarly labeled cities. All indicator systems measure performance related to energy and climate change. Fewer, but still a majority, measure air quality and land use impacts. Even fewer, but still a majority, measure water quality and social health impacts. Waste, transportation, and economic impacts are least commonly measured, but nevertheless are measured by a majority of indicator systems. Despite some consensus on the most important general categories to be measured, there is little consensus about the priority issues to be evaluated in each category. There is also little agreement on the methodology by which indicators for each of these areas should be chosen other than relying on data that are already available and on expert opinion regarding what indicators can best be used to measure progress. Threshold benchmarks are not commonly used, and there is little agreement on how indicators or indicator categories should be weighed against each other in forming an aggregated score that could be assigned to a city if a single summary indicator is desired.

Five case studies are examined in Part III of this report: Stockholm, Sweden; New York City, New York, U.S.A.; San Francisco, California, U.S.A.; Portland, Oregon, U.S.A.; and Vancouver, British Columbia,

Canada. These case studies show that even geographically and economically similar cities in Western Europe and North America approach sustainability and the eco-city concept from different perspectives. These perspectives are influenced by the relationship between each place and its population as well as by physical and political limitations on each city's government. Although the case studies are impressive, the question remains whether the efforts they describe are sustainable and whether their lessons are applicable to the very different geographic, social, economic, and political contexts in China.

Overall, we find that the lack of consensus on the definition of eco-, green, and sustainable cities is driven by a lack of empirical data from long-term case studies as well as by the fact that efforts to develop and evaluate such cities are embedded in political and social goals and priorities.

We conclude that the development of a low-carbon eco-city evaluation scheme in any jurisdiction should begin with an examination of the goals articulated in that region's most recent urban development plans. These goals should then be expanded based on consideration of common indicator categories used internationally and examples of successful planning models. This will enable the region to learn from and add to international policy and technology development efforts. The process of developing eco-city plans and metric systems will be incremental as cities tailor policies and practices to specific local circumstances and changing external factors such as technological developments and economic changes.

TABLE OF CONTENTS

EXECUTIVE SUMMARY	I
PART I: LITERATURE REVIEW – FROM “GARDEN CITY” TO “ECO-CITY” AND BEYOND TO “SUSTAINABLE,” “RESILIENT,” AND “SMART” CITIES	1
1. RADICALLY HEALTHIER CITIES: GARDEN CITIES IN THE LATE 1800S AND EARLY 1900S	3
1.1. GARDEN CITY ELEMENTS	3
1.2. GARDEN CITY CONSTRUCTION AND THE ADVENT OF GARDEN SUBURBS.....	4
1.3. THE MARKET RESPONDS TO THE POST-WAR SUBURBAN EXODUS	6
2. THE ENVIRONMENTAL MOVEMENT AND THE SHIFT FROM HEALTH TO ECOSYSTEM INTEGRATION DURING THE LATTER HALF OF THE 1900S	8
2.1. ENVIRONMENTALISM, QUANTIFICATION OF EFFECTS, AND REINTEGRATION OF NATURE IN URBAN AREAS	9
2.2. COMPUTER TOOLS AND SCENARIO-BASED PLANNING	10
2.3. EXPLORATION OF THE SOCIAL CHARACTER OF PLANNING, AND CHANGING THE RELATIONSHIP BETWEEN THE PLANNING PROFESSIONAL AND CITIZENS	11
2.4. ENVIRONMENTALISTS AT THE FRINGE: LOW-IMPACT COMMUNITIES APART FROM CITIES.....	12
3. THE RISE OF SUSTAINABILITY, AN EXPANDED DEFINITION OF PURPOSE DURING THE 1980S AND 1990S, AND THE SPREAD OF PLANNING STRATEGIES	13
3.1. THE SUSTAINABLE CITY AND GLOBAL ENVIRONMENTAL SUSTAINABILITY	14
3.2. CITY-LEVEL SUSTAINABLE DEVELOPMENT IN EUROPE AND THE “NATURAL STEP” SYSTEM	15
3.3. JAPAN’S ECO-COMMUNITIES	17
3.4. THE SUSTAINABLE CITY AND NATIONAL SOCIAL HEALTH IN THE UNITED STATES	18
3.5. NEW URBANISM IN THE UNITED STATES AND PUBLIC TRANSIT-ORIENTED CITY PLANNING FOR THE SUBURBS	19
3.6. INNER-CITY SUSTAINABILITY	19
3.7. THE SUSTAINABLE CITY AND REGIONAL ECONOMIC SUSTAINABILITY	20
3.8. DOES AN ECO-CITY DIFFER FROM SUSTAINABILITY THEORY?	20
4. CLIMATE-CHANGE-RESILIENT CITIES IN THE 2000S	21
5. SHIFT TOWARDS SMART CITIES? (~2008–ON)	21
6. MEASURING THE ECO-CITY – DESIGN PRINCIPLES TO PERFORMANCE CRITERIA	22
7. CONCLUSIONS.....	24
PART II. MEASURING THE ECO-, SUSTAINABLE, OR GREEN CITY.....	26
1. METHODOLOGY	27
2. THE STRUCTURAL FOUNDATIONS OF INDICATOR SYSTEMS	29
2.1. UNITS OF ANALYSIS: WHAT IS A CITY?	29
2.2. USE OF POLICY-BASED INDICATORS.....	33
2.3. INDICATORS VERSUS INDICES.....	34
2.4. BUILDING AN INDICATOR SYSTEM	35

2.4.1. Indicator selection criteria	35
2.4.2. Benchmarks.....	38
2.4.3. Weighting of indicators.....	39
2.4.4. Other issues: verifiability and qualitative metrics.....	42
3. KEY FINDINGS REGARDING INDICATORS AND INDICATOR CATEGORIES.....	42
3.1. FREQUENCY OF USE OF SPECIFIC INDICATORS	42
3.2. FINDINGS: INDICATOR CATEGORIES	43
3.2.1. Energy and climate	44
3.2.2. Water quality, availability and sanitation.....	47
3.2.3. Air Quality	49
3.2.4. Waste	51
3.2.5. Transportation	53
3.2.6. Economic health.....	56
3.2.7. Land use and urban form	58
3.2.8. Social health indicators	61
4. LIMITATIONS OF THIS RESEARCH	64
PART III: CASE STUDIES OF CITIES PURSUING ECO-CITY GOALS	65
1. CASE STUDY 1: STOCKHOLM, SWEDEN: WORLD-RENOWNED CITY IMPROVEMENT EFFORT CENTERED ON ECO-DISTRICTS	68
1.1. INTRODUCTION	68
1.2. ECO-DISTRICTS.....	68
1.3. PLANNING.....	68
1.4. CHARACTERIZATION BY LOW-CARBON ECO-CITY PRIMARY CATEGORIES, TECHNOLOGIES AND POLICIES, AND RESULTS	70
1.4.1. Energy and climate	70
1.4.2. Water	72
1.4.3. Waste	73
1.4.4. Air.....	73
1.4.5. Transportation	73
1.4.6. Land use	75
1.4.7. Economy and social goals	76
2. CASE STUDY 2: NEW YORK: DISPERSED CITY IMPROVEMENT PROJECTS IN THE MEGA-CITY	78
2.1. INTRODUCTION	78
2.2. PLANNING.....	78
2.3. CHARACTERIZATION OF LOW-CARBON ECO-CITY CATEGORIES, TECHNOLOGIES AND POLICIES, AND RESULTS	79
2.3.1. Energy and climate	79
2.3.2. Water	82
2.3.3. Waste	83
2.3.4. Air.....	85
2.3.5. Transportation	86
2.3.6. Land use	88
2.3.7. Economic and social goals	90
3. CASE STUDY 3: SAN FRANCISCO CA: CITY-DIRECTED ECONOMIC INCENTIVES FOR GREEN BUSINESSES.....	92

3.1. POLICIES AND MEASURES	92
3.2. RESULTS AND FUTURE GOALS	93
4. CASE STUDY 4: PORTLAND OR: INTEGRATING BICYCLES INTO EVERY CITY SPACE	95
4.1. POLICY AND MEASURES.....	95
4.2. RESULTS AND FUTURE PLANS.....	97
5. CASE STUDY 5: VANCOUVER, B.C.: DENSITY PLANNING	98
5.1. POLICIES AND MEASURES	98
5.2. RESULTS AND FUTURE GOALS	99
APPENDIX A: EXAMPLES OF DESIGN PRINCIPLES FOR ECO- AND SUSTAINABLE CITIES	101
REFERENCES.....	105

List of Tables

Table 1. Summary of Indicator Systems Reviewed.....	28
Table 2. Factors Determining Chinese City Type	31
Table 3. Examples of Variables for Cluster Analysis.....	32
Table 4. Indicator Selection Criteria.....	37
Table 5. Example of an Implicit Weighting Scheme in the Economic Intelligence Unit's European Green Cities Index.....	41

List of Figures

Figure 1. McHarg's planning overlays evaluating a potential urban site – scale in miles	10
Figure 2. Statutory Urban Areas in China.....	30
Figure 3. European Green Capital Award, 2010	68
Figure 4. The Hammarby Model	70
Figure 5. 2009 New York City-wide GHG Emissions by Sector.....	79
Figure 6. Impact of Buildings in New York City	80
Figure 7. Diversion Rate by Waste Stream	84
Figure 8. New York City Traffic Volumes and Transit Ridership.....	88
Figure 9. Cleantech Venture Investment Amount by Metro Area.....	94
Figure 10. Portland's 2010 Bike Network Figure 11. Portland's Expected 2030 Bike Network	96
Figure 12. Vancouver's 2008 GHG Emissions Sources	98

Acronyms

C	centigrade
CHP	combined heat and power
CLC	county-level city
CO ₂	carbon dioxide
CO ₂ e	carbon dioxide equivalent
dB(A)	A-weighted decibel
DPSIR	driving force-pressure-impact-state response
EIU	Economist Intelligence Unit
ELP	Environmental Load Profile
EPI	Environmental Performance Index
ESCO	energy service company
ft ²	square foot
GCTF	Green Codes Task Force
GDP	gross domestic product
GGBP	Green, Greater Buildings Plan
GHG	greenhouse gas
GIS	geographic information system
kg	kilogram
km	kilometer
km ²	square kilometer
kWh	kilowatt hour
LEED	Leadership in Energy and Environmental Design
m ²	square meter
m ³	cubic meter
METI	Ministry of Economy, Trade, and Industry
MOE	Ministry of the Environment
MTA	Metropolitan Transit Authority
NO _x	nitrogen oxides
NO ₂	nitrogen dioxide
O ₃	ozone
OECD	Organization for Economic Cooperation and Development
PLC	prefecture-level city
PM _{2.5}	particulate matter smaller than 2.5 microns
PM ₁₀	particulate matter smaller than 10 microns
PV	photovoltaics
RMB	Renminbi
SFDE	San Francisco Department of the Environment
SO ₂	sulfur dioxide

Part I: Literature Review – from “Garden City” to “Eco-City” and Beyond to “Sustainable,” “Resilient,” and “Smart” Cities

Summary of Part I: This section reviews the integration into urban planning in the United States and United Kingdom of ideas of ecological, economic, and social health and briefly introduces modern eco- and sustainable city programs found in other parts of Europe and Japan. Urban planners addressing the concept of sustainability in cities have moved through five general stages of focus since the industrial revolution: 1) integrating an agrarian settlement mode into city-like settlements to increase health and reduce social discord related to poverty; 2) protecting human, local environmental, and ecosystem health; 3) protecting global environmental health; 4) integrating broad concepts of social health, such as economic and social equity; and, most recently, 5) incorporating climate change resilience and technological advances. This evolution has produced a diversity of concepts, many of which are integrated into eco-city theory by proponents despite a lack of consensus on the exact detail of each or the priority of strategies to pursue. Broadly, an eco-city should incorporate plans, measures, technologies, and operational strategies to increase all aspects of environmental, social, and economic health; narrowly, these goals should be accomplished primarily by efforts to conserve natural resources, reduce fossil fuel use, increase density and reduce automobile use, reduce and recycle waste streams, integrate nature into cities, shift the economy toward the service sector and high value-added technology creation, build diverse spaces that offer value to all population subgroups, and actively seek and support community involvement in city improvement efforts.

The term “eco-city” is still relatively new, and researchers and governments use it to describe a multitude of ideas and concepts (Van Dijk, 2011; Joss, 2010). Synonymous concepts such as “sustainable city,” “low-carbon city,” “eco-community,” “green city” are used interchangeably with the term “eco-city.” These terms all describe attempts at the city level to resolve economic, social, and environmental conflicts that have arisen primarily due to the consequences of economic growth and demographic change. Despite its origins in the late 1800s, eco-city planning is not a singular body of thought but an amalgamation of various planning modes that have arisen in response to the side-effects of economic development during the past 150 years. The plethora of ideas and descriptors makes it difficult to formulate a single precise definition. Adding descriptors like “low carbon,” as in the term “low-carbon eco-city,” may prescribe a particular focus for eco-city planning and performance evaluation, but the term eco-city covers a much broader range of environmental, social, and economic issues than the reduction of carbon dioxide emissions.

Although many eco-city concepts can be found in planning theories from the past, until recently they remained only concepts. Mark Roseland, scholar of the eco-cities movement, notes, “throughout the 1980s and 1990s, the term ‘eco-city’ remained mainly a concept, a collection of ideas and propositions about sustainable urban planning, transportation, housing, public participation and social justice, with practical examples relatively few and far between” (Roseland, 1997; Joss, 2010). Several different schools of thought in urban planning have addressed elements of the eco-city concept, especially in the

United States and the United Kingdom. However, a review of the sustainable city movement in the United Kingdom found that, “notwithstanding examples of good practice, advocacy rather than research has often characterized the debate” about what “sustainable city” means (Jenks and Jones, 2010). During the past decade, there has been renewed effort to apply sustainable city theories to projects at the neighborhood, district, and city scale. The most promising of these projects are just getting started, many of them in Europe, Asia, Africa, and South America. Ironically, relatively few projects are occurring in the United States and the United Kingdom where much of the sustainable city planning theory originated (Joss, 2010).

The lack of eco-city case studies might result from the cost and up-front planning involved in meeting the ambitions laid out in eco-city theory. Past projects that attempted to manifest eco-city concepts were on a scale that required an unworkable amount of time and investment, particularly given cyclical economic and political changes (Hall, 2002). As a result, past sustainable city and eco-city-like projects were hindered by reduced budgets, time constraints, and political changes. The few available case studies of both new and existing settlements represent a diversity of technologies and procedures rather than a consistent picture of established best practices. Moreover, the few case studies that exist reflect the state of technology at the time a project was implemented, the geographic and climatic diversity of the project location, and specific local governance structures and processes.¹

Although its outcomes have been diverse, city planning in the 20th century has been driven by a consistent set of problems that industrializing cities have faced for the past 150 years: severe environmental degradation and consequential health and ecological impacts on citizens and natural resources, extreme poverty and inequity because of inconsistent economic activity, and social dissolution (Hall 2002). In some instances, solutions implemented to address these issues have only exacerbated the problems. Indeed, theorists have often used the term eco-city and its historical antecedents in reaction to what were perceived as the major planning mistakes of the immediately previous era, and this gradual development of solutions is perhaps a reason for the great diversity in today’s eco-city theories. Therefore, our review begins with a chronological description of how the constellation of concerns encompassed in the eco-city concept have been integrated over time into urban planning, public policy, and related fields. Despite our attempt to organize the development and integration of eco-city concepts, we acknowledge that, as Hall (2002) observes, these schools of thought “do not readily submit to any schematic ordering [and] crisscross in a thoroughly disorderly and confusing way.”

Human beings have been working since ancient times to solve issues of urban resource scarcity, energy use, environmental quality, and quality of life; past efforts were often limited to protecting the highest social classes (Spirn, 1985; Diamond, 2005). Our chronology focuses on the time period since the industrial revolution because the concurrent rise of the middle class and dramatic expansion of technological capabilities during this time period pushed Western city managers and planners to consider the well-being of all city inhabitants, with a particular focus on providing a minimum standard

1 Part III of this report presents case studies of five municipalities currently pursuing eco-city goals.

of living for non-elite classes. Although a fully comprehensive literature review is beyond the scope of this report, we identified in the literature five semi-distinct eras in the development of what is today known as the eco-city concept. For convenience, we discuss these five eras chronologically, but they interweave and overlap over time (Hall, 2002). Moreover, many planners align themselves with more than one of the five concepts we describe, or combinations of these concepts.

1. Radically Healthier Cities: Garden Cities in the Late 1800s and Early 1900s

Richard Register is commonly acknowledged as having introduced the term eco-city in his 1987 book *Ecocity Berkeley: Building Cities for a Healthy Future* (Register, 1987). However, Register's concept and other similar ideas share a common origin: the late 1800s' vision of the garden city, described by Ebenezer Howard in his book *Garden Cities of To-morrow* (Howard, 1898; Register, 1987; Hall, 2002). Although others articulated similar planning philosophies during the 1800s, Howard is credited as the originator of a holistic vision of a new type of city development that, through integrating rural settlement types and industrial urbanization through upfront planning, eliminated the contradictions among social groups, economic development, and environmental quality (Hall, 2002; Wheeler and Beatley, 2004). Howard's vision remains radical even today because it requires the high-speed creation of completely new large-scale developments and new societies of volunteer self-governing commonwealths. No garden city was ever built completely true to Howard's vision, but several attempts were made and subsequently diminished as implementation barriers necessitated reductions in scale and components. Indeed, much of the evolution of eco-city theory has been characterized by development of radical visions such as Howard's, followed by pragmatic adaptation of these visions as unexpected barriers prevented the theory from being implemented in its original form.

1.1. Garden city elements

Howard's vision was of new towns and cities of about 30,000 residents each, built in series and according to a radial layout plan in which each city's residents lived in close proximity to self-sufficient industries, community services, and agriculture. To ensure that cities would not exceed their resource constraints, the growth potential of each city was limited by a "green belt" of non-developed areas surrounding the city. To prevent the accumulation of speculative investment capital and the social discord resulting from conflicts of interest between landlords and tenants, each city was to be collectively owned by its occupants. Physically, the garden city was to be laid out in a wheel-and-spoke pattern of sectors that would expand over time as small towns and villages surrounded a larger central city.

The main purpose of this model was to allow Britain's growing worker class, increasingly trapped in poverty in the unsanitary and overcrowded slums of industrial centers, an alternative that balanced the social and economic benefits of cities with the healthful effects of living in the countryside (Howard, 1898; Wheeler and Beatley, 2004). A cleaner environment, efficient city sanitation services, and sufficiently spacious housing were the main strategies envisioned to reduce the harmful health effects

of the urban environment. Economic growth would rely on each occupant becoming an artisan entrepreneur, producing the highest-quality goods for primary use in the community, with potential for export sales. Perhaps most important to Howard's vision was a strong interest in equity to reduce class conflicts and create sustainable community economic growth. Although garden cities would be newly built on purchased property, they were to be publicly owned by occupant collectives, and, after the original capital investment was paid off, rents paid by businesses and residents were to be reinvested in municipal works rather than going to investors (Hall, 2002; Basiago, 1996).

1.2. Garden city construction and the advent of garden suburbs

Howard and his followers built two British cities using the garden city model: Letchworth in 1903 and Welwyn in 1919. These cities resemble the residential components of the garden city model in several ways but are much smaller and do not fully integrate the agricultural and commercial components necessary to creating the thriving local economy envisioned by Howard (Hall, 2002). Perhaps a sign of their sound planning, these towns still exist today and have largely avoided the economic pains that have hit most other British towns (Register, 2002). Many new developments built in the United States and United Kingdom during the same era, in part to provide housing for relocated urban poor, borrowed from Howard's garden city theory in name but similarly largely eliminated the local industries and resident-ownership components. As a result, these settlements were reduced to a new and very different development form: the garden suburb (Hall and Ward, 1998; Hall, 2002; Wheeler and Beatley, 2004). In these developments, built for government-subsidized relocation schemes and linked to central cities by light rail, we find linear real estate development along transit lines and two factors that are the reverse of eco-city goals: the antecedents of sprawl development and its component wide setbacks, single-family home oriented layouts, and large plot sizes; and the rapid incursion of urban development on traditionally rural environments.

Despite incomplete implementation of garden city theory in the United States, Canada, Australia, and South America (Register, 2002), many of Howard's ideas live on with widespread support today. These include his focus on human health as a reason to pursue high environmental quality; restriction of outward sprawl development in peri-urban green belts; proximity of local jobs for residents; and means to enhance social equity among all citizens.

During the first two decades of the 1900s, new planning strategies were implemented in fast-growing American cities. Three principles that evolved during this time and have become a part of the eco-city concept are neighborhood-unit-based planning, social and geographic survey-based planning, and residential area layouts that restrict vehicle access and provide quiet streets (Hall, 2002). During this time period, methods for data-based planning arose and quickly gained prominence, resulting in the fast uptake of two types of planning surveys: population and geographic. Both types of data collection gained recognition as they were increasingly employed by Patrick Geddes and the newly formed Regional Planning Association of America, which worked to standardize their practice. The first modern social survey for the purposes of city governance planning had been undertaken in London during the

late 1880s and created shockwaves in the governance community (Hall, 2002). In addition to using innovative methods of classifying populations by income and activity, the London survey was highly valuable to city managers because it presented statistical data in color-coded maps that allowed viewers to visualize the relationships between many social ills and city geography. Geddes enthusiastically embraced this methodology and continued to pioneer the concurrent use of maps and surveys to combine population and geographic data. Geddes' main contention was that planning must start with a survey of the natural resources of a region, the human response to those resources, and the cultural landscapes created by this relationship. This principle remains an important part of city planning today and an essential precept of eco-city planning (Hall, 2002).

Another development in American planning during this period that has worked against the achievement of eco-cities is the concept of semi-permanent land use zoning that prioritized the separation of any commercial or industrial activities from residential areas. Compared with the government-led slum clearances and rehousing subsidy schemes in the United Kingdom, the United States approach to the problems of urban environments has traditionally been decidedly more market-oriented. The approach in the early 1900s was to regulate developers' actions by using zoning regulations to restrict land uses. Based initially on the exclusion of disfavored land uses (often with a strong element of race-based exclusion) to maintain long-term residential property values, exclusion-based land use zoning became a ubiquitous feature of American planning after the World War I. The type of zoning code that eventually dominated American cities, called Euclidian zoning, prioritized residential land uses and strictly separated land use functions (e.g., housing kept separate from commercial districts). In this system, zoning decisions were rarely tied to comprehensive city plans, which resulted in the low-density residential sprawl that is common in the United States today and an inability for local governments to site and scale infrastructure and common goods facilities in relation to the future needs of residents (Wheeler and Beatley, 2004).

Inner city planning during this period was largely dominated by the City Beautiful movement. Although not considered a singular school of thought, modern scholars find that many planners in this period advocated for building facially beautiful inner cities filled with monuments to inspire commerce and influence residents to live morally upright lives. These efforts are derided by modern scholars because of their tendency to merely hide, rather than resolve, the continued degradation, overcrowding, and increasingly strife-ridden city slums behind the beautiful facades (Hall, 2002). Although this movement was decidedly not a part of the garden city movement, they share an emphasis on creating social harmony through urban planning. However, these schools differed greatly in this area – whereas the connection between daily interaction, economic cooperation, and land use planning was more deeply discussed by garden city theorists, works in the City Beautiful movement were considerably more speculative in how classical architectural aesthetics would inspire economic development and imbue citizens with morals and ethics. Albeit unsupported by empirical data, some sustainable and eco-city theory even today echoes of the core assumption of this school of thought – that the city landscape itself has the ability to, without supportive social policies, inspire residents to resolve conflicts, reduce discord, and lead lives that are fully concordant with dominant social norms.

1.3. The market responds to the post-war suburban exodus

The failure of the garden city movement and the incomplete implementation of Geddes' regional planning methodologies failed in large part due to a coincidence of timing. The world wars and the Great Depression in the United States prevented the kind of dramatic change in consumer expectations and economic relationships, guided by focused government action, that would have been necessary for implementation of garden cities.

In the United States, centrally-supported urban planning research grew during this period, with many publications and studies supported directly by the federal government. Landmark nationally funded reports such as the 1935 *Regional Factors in National Planning and Development* (United States National Resources Committee, 1935), the 1937 *Our Cities: Their Role in the National Economy*, (United States National Resources Planning Board, 1937), and other publications of the New Deal era explored the nature of city growth and its relationship to economic and social goods; however, few efforts attempted to apply the findings of these publications to city planning activities in the United States. Although astute in their use of survey methods and calling for many garden city elements, these reports could not account for approaching changes caused by new technologies, such as the automobile and ubiquitous electricity, and they were quickly dated by this lack of foresight.

Lewis Mumford, who was an assistant of Geddes, an advocate of garden cities, and a leader of mid-century U.S. urban studies, established another foundational concept of the eco-city theory during this period. Mumford advocated use of high technology to mediate between nature and urbanites. Mumford is an earlier pioneer of the kind of ecological analogy that has become common in eco-city planning: he discussed his concepts in terms of biology, for example looking at how a mixture of technological solutions could make buildings and spaces function like integrated living machines and thus make "production and distribution directly subservient to biotechnic standards of consumption." Mumford also pioneered the organic analogy found in many sustainable urban planning writings of today, advocating for cities built and operated based on "organic order" in which city dwellers and the city itself self-regenerated and adapted based on planned active relationships with the rest of the environment (Mumford 1938).

As the economies of the west recovered during the post-war period, governments once again started to explore city planning as a means of implementing social policy. Despite the in-part government funded academic advances of the Great Depression and wartime periods, technological advancements, political turmoil, and demographic changes drove the real estate market to respond much faster than governments to the desires of the rising middle class. Urban planning practice increasingly diverged to serve two very different populations.

On the one hand, inner city planning became dominated by the Modernist movement. Modernism as it pertained to architecture and city-planning entailed the use of new building forms and construction technologies, especially automobile-centric planning, pre-fabricated housing, steel-frame skyscrapers, and reinforced slab concrete construction, and the integration of new automated consumer product

technologies with the built environment to prioritize human desires for convenience, the aesthetic beauty of monumental scale, and housing distribution mechanisms less reliant on the purchasing power of the individual. The most notable figure in this movement, Le Corbusier, developed several visions of large scale green field developments founded on homogenous high-rise residential skyscrapers, separated automobile and pedestrian spaces, expansive park-like green spaces between buildings, and non-market residential unit distribution mechanisms. Although few of Le Corbusier's projects were built, his influence on architecture and urban planning cannot be understated (Hall, 2002). Most notably, his assumptions of the ability of modern, dense architecture and single-use superblocks to conveniently, safely, and cheaply house the urban lower and middle classes resulted in the highly unsuccessful large-scale, high-rise affordable housing residential developments constructed during the mid-century in the United States and the United Kingdom.

Outside of American cities, much private investment and effort focused on small-scale, speculative development of automobile-dependent suburbs along urban peripheries (Hall, 2002). Four factors combined to result in the suburbanization of the United States during this time period: the influx of soldiers returning home from World War II, the resulting baby boom, and the high-speed increase in the proportion of new families; the increasingly unsavory character of urban spaces as wealthy residents and economic activity moved to city outskirts; the dramatic expansion of automobile ownership and the national highway system; and the creation of national-government backed single-family home ownership financing subsidy programs (Hall, 2002; Register, 2006). Due to now ubiquitous Euclidian zoning, these new families moved to newly-built residential areas where there were few local jobs and few geographic or cultural connections to surrounding areas. As a result, vast landscapes were covered with subdivision communities far from both jobs and public transit, and subdivision residents increasingly used cars to commute to places of employment, commerce, and recreation (Register, 2006).

In the United Kingdom, theoretical research during the Great Depression was more often focused on the post-war rebuilding effort. This effort is marked by the highly successful expansion and rebuilding of London using many garden city ideals. A regional plan, undertaken by a new national-level committee with the power to overrule local government resistance, pieced together planning best practices of the era: survey-based planning; a green belt between the city and transit-linked multi-use satellite towns; public land purchase schemes with strong oversight; clear links to a strong national-level planning process; neighborhood-unit planning and road hierarchies; differentiated development designs for different communities; and pragmatic oversight by semi-private enterprises that prioritized corporate profitability (Hall, 2002). Car-based suburban developments were in demand in England as they were in the United States, but English society had more strongly entrenched interests in maintaining rural culture and scenery than American society, and these groups advocated effectively for green belts and urban growth boundaries (GLRPC 1929, 1933). The Greater London Plan was largely successful, and the "new towns" developed during this period remain outstandingly livable communities today (Hall, 2002).

However, aside from the Greater London Plan, the garden city and its constituent concepts were only sparingly incorporated into national-level planning activities in England and elsewhere; most notable among the exceptions is the development of Stockholm, Sweden, as discussed below. However, most

European development concentrated on building modernist-style high-rise apartment blocks to house urbanites (Hall, 2002). The explosion in car ownership after World War II and the dismantling between the two world wars of the light urban rail lines on which the garden city and similar visions had rested marked the end of eco-city-like urban planning during the middle of the 20th century. Sprawl, especially in the United States but also in Europe, served both social and economic functions, especially in moving the country's economy away from the war effort by creating consumer-oriented manufacturing activity. Concurrently, sprawl decimated city populations and the jobs that depended on urban industrial economic activity. This set the stage for the patterns of suburbanization and emptying of urban core areas that unfolded during the post-war period.

2. The Environmental Movement and the Shift from Health to Ecosystem Integration during the Latter Half of the 1900s

The rise of the environmental movement in the middle of the 20th century greatly influenced the fields of urban design, landscape design, and architecture. Contributions from biology, chemistry, and other natural sciences strengthened the perspective of cities as ecosystems and drove a shift away from exclusive theoretical concern for the social effects of poor sanitation, increasing economic development, and mitigating blue-collar worker malaise. The new focus was on practices and strategies to alleviate local human and ecological health impacts from water and air pollution and the use of toxic substances. These movements, like the garden city movement, developed as a direct reaction to the social and environmental ills resulting from unplanned, rapid development of the previous era, especially in once-rural suburban communities. Unlike the garden city movement, these efforts were to a much greater extent informed by empirical sciences rather than speculation.

New planning strategies were also developed and perfected in this period. The new emphasis on the human-ecosystem relationship produced three innovations in urban and landscape planning: the use of planning map overlays to visually present geographic and resource data at the local and regional level; the use of computer models to calculate current and future transportation movements, resource demands, and impacts; and a focus on improving urban residents' ecosystem awareness through landscape architecture. At the same time, research during this period began to quantify the beneficial effects of planning principles developed since Howard: reduced need for personal transportation in multi-use, compact communities with integrated transportation infrastructure; distribution of clean water, metering of water use, and centralized treatment of wastewater; reduction of waste and the introduction of recycling and other appropriate treatment of wastes; emphasis on renewable energy use and efficient energy consumption; construction of energy-efficient "green" buildings; and integration of biodiversity, natural features, and green spaces in urban landscapes to enhance environmental consciousness. The extreme reactionary position of much of the eco-city-like theory of this period can be perceived in the anti-freeway movement that spread in North America in the 1960s and the development of stand-alone, self-sufficient rural communities based on "back-to-nature" concepts.

2.1. Environmentalism, quantification of effects, and reintegration of nature in urban areas

Rachel Carson's 1962 book *Silent Spring* is often hailed as the beginning of modern popular environmentalism. Carson was one of the first scientists to help a general audience understand the interactions between human choices and ecosystem vitality. Her book made clear that anthropogenic disruptions of one part of an ecosystem can have large negative effects on the natural systems of inherent value to human health and happiness. At the same time that Carson's book was published, cities were becoming objects of criticism and pessimism as new technologies and ways of urban living made them, in the view of some critics, too disconnected from natural systems and too supportive of detrimental social forces such as fascism and social instability.

The increasing awareness of the ecological character of cities and the desire to better integrate natural systems in city planning led urban planning and landscape architecture scholars to construct new analytic systems to quantitatively describe urban resource relationships. Wolman's quantitative analysis of city systems inspired the development of a method for quantifying the resources and energy consumed by a city. Wolman's "urban metabolism" model attempted to calculate "all the materials and commodities needed to sustain a city's inhabitants and home, at work, and at play" (Wolman, 1965). In his original study, Wolman used U.S. data to determine, for a hypothetical American city of one million people, the per-capita inflow of water, food, and fuels, as well as outflows of sewage, waste, and air pollution (Kennedy, et al. 2011). Wolman's method used solar energy equivalents (in "emergy" units) as an all-encompassing, final unit of analysis. Although there was little research on urban metabolism during the 1980s, a resurgence in the field during the 1990s and 2000s, discussed below, inspired urban sustainability indicator systems and has even been applied directly to urban planning processes.

Another important examination of the ecological character of cities that was published during this period is McHarg's 1969 book *Design with Nature*, which emphasizes the need to plan new developments that appreciate and are integrated with a site's ecological and environmental conditions. This more aesthetic appreciation of environmental and geographic features is the antecedent to much of the attention to region-appropriate public green space planning in eco-city theory.

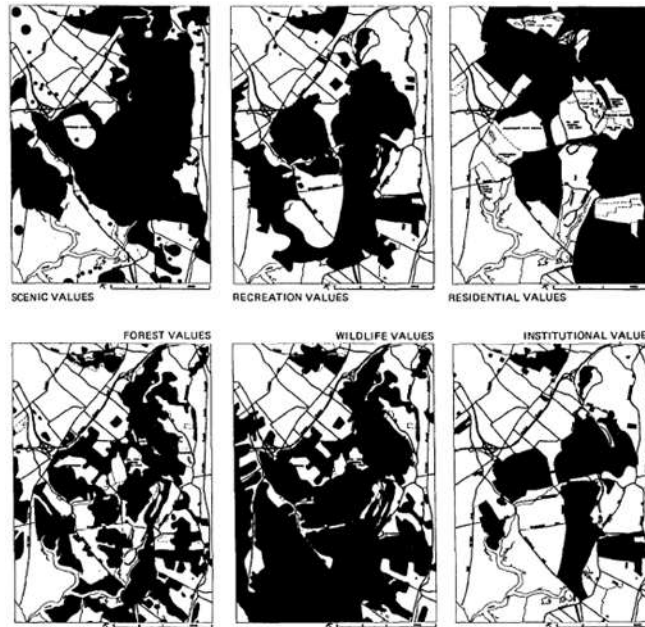


Figure 1. McHarg's planning overlays evaluating a potential urban site – scale in miles

Source: McHarg, 1969

McHarg (1969) developed a system of analyzing a site's uses and natural characteristics and presenting in map form a qualitative and quantitative understanding of a place's interactions with its environment. McHarg's overlays, an example of which is shown in Figure 1, led directly to the development of geographic information system computer programs and had a significant impact on analysis of spatially overlapping patterns of natural and human-induced uses and flows in urban and architectural planning and design (Basiago, 1996).

2.2. Computer tools and scenario-based planning

An extension of Wolman's and McHarg's quantitative works uses computers to calculate the full consequences of ecological damage caused by urban growth. A powerful early example of this methodology can be found in *Limits to Growth* (Meadows et al., 1972). *Limits to Growth* was one of the first computer-based attempts to systematically and mathematically analyze scenarios showing how environmental and resource constraints would significantly influence the development trajectory of humankind in the near- and long-term future. The stock and flow variables used in the study's systems dynamics models could be considered an early generation of sustainability indicators.²

Similar to *Limits to Growth*, an important early study quantifying the impacts of urban design decisions on energy and materials demand was *The Cost of Sprawl*, a 1974 report by the U.S. Council on Environmental Quality, U.S. Department of Housing and Urban Development, and U.S. Environmental

² The authors wish to thank Artessa Niccola Saldivar-Sali of the World Bank's Urban Development and Local Government Unit for this insight.

Protection Agency (Real Estate Research Corporation, 1974). *The Cost of Sprawl* report measures the impacts of low-, medium-, and high-density urban designs on schools, fire and police services, government facilities, roads, utilities, energy consumption, water use, air pollution, and water pollution. Because of the oil embargoes of the early 1970s, *The Costs of Sprawl* received significant attention. It was one of the first quantitative assessments comparing urban designs with each other and calculating the large and widespread effects of suburban sprawl on commuters, businesses, investors, innovators, and especially local governments, which had to pay for infrastructure repairs. The U.S. government's support gave the report a prominence rarely enjoyed by urban studies; it and its subsequent revisions are frequently cited as foundational texts in arguments for urban system reform in the United States.

2.3. Exploration of the social character of planning, and changing the relationship between the planning professional and citizens

During this period of increasing popular environmental consciousness and discontent with the results of post-war development, great efforts were made to make the lessons of the history of planning as well as the recent advances in quantitative data analysis more broadly available to the public.

Since the beginnings of slum clearance programs in the early 1900s, the question of how to redevelop the inner city had been a vexing question in the west. Although federal support for inner-city housing was given a large funding and policy boost in the United States in the mid-century and many communities created redevelopment-oriented policies and laws around the same time, few efforts were successful at stemming the middle-class flight out of inner cities and the resulting loss of economic activity. Many slum clearance and relocation projects were marred by questionable politics, poor economics, and social upheaval; few examples of high quality inner city redevelopment exist before the late 1990s. The primary regulatory means by which inner-city redevelopment was to occur, the use government police powers to confiscate misused land in central cities and create incentives for private redevelopment, can theoretically produce many benefits such as decreasing traffic congestion, increasing land values, and reducing infrastructure inefficiencies. However, the architectural model upon which many urban renewal schemes were created, the high-rise residential tower, was a social failure that failed to attract all but the most impoverished citizens. Furthermore, urban renewal, as these slum clearances and similar projects came to be called, was disastrous for the poor, who were forcibly removed from redeveloped areas and packed into badly designed and constructed buildings that promoted crime, violence, and despair (Glaeser, 2007; Hall, 2002).

As housing projects for the poor began to be seen as generators of social dysfunction, critics arose to advocate for dramatic change to the institutions and processes of planning. Jane Jacobs is the best known of the critics of mid-century planning for her discussion of the negative social effects of high-rise residential redevelopments in New York. She advocated for density that was sensitive and responsive to the diverse social and economic needs of city occupants (Jacobs, 1961).

Other later theorists in this vein looked at the contemplative and spiritual impacts of natural features (or the lack thereof) on urban residents and their cultures. For example, Spirn (1985) used McHarg's *Design with Nature* principles to focus on the "landscape literacy" effects of urban design deep within cities, emphasizing that a greater use of natural features within cities might result in better social welfare and better environmental management by every individual. Exploring the connections among individual cognition, lifestyle quality, community activity, and urban spaces was also a priority for the Community Design Movement, a school of planning that arose during the 1970s and 1980s. This anarchistic, small-scale-development-oriented, community-driven planning paradigm presumed that the planner's own (often elitist) biases would diminish the utility of top-down planning and reduce the likelihood that a community would optimize the use of public spaces. Therefore, this school advocated for placing the planner at the bottom, rather than the top, of the plan-creation hierarchy (Hall, 2002). This movement fused planning with advocacy for environmental justice and racial equity and introduced what has become a common principle of eco-city advocacy today: high levels of participation from the local citizens during planning process.

Similarly, during the 1980s and 1990s, eco- and sustainable city planning, especially that aimed at inner city spaces, increasingly responded to many of the above critiques in its acknowledgment of the value of human-scale spaces and its calls for inclusiveness, planning diversity of both spaces and their uses, and planning spaces to seamlessly integrate with people's everyday lives.

2.4. Environmentalists at the fringe: low-impact communities apart from cities

During the mid-20th century, concurrent with the analytical developments described above and the central-city-oriented community design movement, experimentation with alternative community forms arose that can be considered as a subset of the eco-city movement. These alternative communities, generally built by their members in rural or semi-rural areas far from large cities, are widely known today as eco-villages or intentional communities. Some of the earliest examples include the Findhorn Foundation and Community established in Scotland in 1962 and the Arcosanti town complex built in the Arizona Desert in 1970 (Fellowship for Intentional Communities, 2012).³ Communities of this type now number more than 400 throughout the developed and developing world ("What are Eco-Villages?" 2008). Common principles of these settlements include grassroots financial sponsorship by community members rather than governments, small populations (usually limited to fewer than 500 residents), full resident participation in community living activities, an attempt to provide basic consumer necessities within the community rather than depending upon external sources, a strong sense of shared community values, and global community service as research and demonstration sites (Dawson, 2006). In terms of materials use and environmental issues, eco-villages also often strive for local manufacturing using only non-toxic, non-destructive, and non-exploitative products; conservation and reuse, reduction,

³ See the Fellowship for Intentional Communities Eco-village Directory for a list of communities.

and recycling of resources; reliance on renewable energy such as solar; and regeneration and regrowth of natural support systems (Canfield, 1994).

Many eco-village self-sustaining agricultural practices are drawn from Mollison and Holmgren's 1978 small-settlement agriculture planning manual *Permaculture One*. Productive activities, waste streams, and environments in these communities are largely planned to be immediately synergistic with each other to minimize waste and optimize food production decisions. Although largely agriculturalist in its origin, *Permaculture One* introduced a new theory that has had considerable impact on eco-city theory: that waste streams and production practices should be and can be interlinked, especially through recycling and optimizing natural processes like organic decomposition, to dramatically reduce waste. This theory, of cyclical waste reuse, has had a significant impact on industrial systems through the field of industrial ecology and now is spreading to urban planning.

Although self-reliant communities like eco-villages are likely not achievable at the large city scale, they can be incubators of new experimental technologies and might eventually provide interesting social and economic solutions for neighborhood-scale developments in cities or at the suburban periphery. As such, they form a part of the "eco-city ecosystem" in the west, and their presence is strongly felt in places that have developed larger eco-city projects such as Sweden, the United Kingdom, the western United States, and New York state.

3. The Rise of Sustainability, an Expanded Definition of Purpose during the 1980s and 1990s, and the Spread of Planning Strategies

The eco-city concept shares fundamental precepts with the garden city and other city efforts of the past, but the term "eco-city" was first used during the 1980s and 1990s as the attention of developed countries turned to global environmental sustainability, national social health, and concerns about economic sustainability, and is therefore greatly influenced by the intellectual developments of this time period. However, urban planning ideals were pursued differently by different national governments during this period and this diversity of programs also informs the still-indefinite present conceptualization of eco-cities. In Europe, especially Western Europe's capital cities, there was greater consensus on the priorities of global pollution reduction, resource sustainability, and urban planning. In Japan, efforts revolved primarily around developing city linkages to share best practices and waste reduction and treatment, overseen by the central government. And in the United States, this period was marked by a divergence of city planning efforts between planning for better suburban developments and a continued effort to revitalize city cores, with little coherent ties between the two areas.

This period is also characterized by a re-embracing of the multi-factor, large-scale, integrated problem-solving that characterized the garden city movement. Social, economic, and environmental problems were seen as highly interlinked, and theories quickly expanded to consider not only ecosystem-like flows and resource conservation but also the notion that sustainability efforts should prioritize the enhancement of public good and should incorporate social and economic issues such as employment,

space access equity, local economic growth, and concepts like the “rebirth of civic community” (Beatley and Manning, 1997; Newman, 1999).

3.1. The sustainable city and global environmental sustainability

Sustainable development first appeared in the environmental planning and policy literature during the 1970s and became a significant theme by the 1980s (Beatley and Manning, 1997). Inherent in sustainability is a concurrent focus on local, regional, and global issues and a local population’s relationship with these issues.

Buoyed by the quantitative studies of the 1970s that directly linked development to local and global environmental and human health outcomes, both quantitative and qualitative approaches to defining and measuring sustainability blossomed during the 1980s. As scientists became more aware of the regional and global consequences of air pollution, the environmental movement shifted away from the 1950s’ and 1960s’ focus on localized effects of air, water, and toxic pollution issues to global impacts of industrialization. This era marks the first global accords to deal cooperatively with the environmental impacts of development. For example, research into the causes and consequences of acid rain during the 1970s led to cooperative domestic and international efforts to stop the industrial sulfur dioxide emissions that caused it. The Montreal Protocol gathered developed nations together during the late 1980s to prevent ozone depletion, and the 1992 Rio Earth Summit marked the start of the current era of international focus on global climate change. Global concerns about biodiversity losses also arise during this period (Wilson, 1988). In urban planning, although earlier concerns about local urban pollution, sprawl, and congestion continued to be priorities, other concerns became increasingly important with the advent of new research and advocacy, especially originating from international organizations. Increased interest in global sustainability during this period pushed urban planners and others to expand the boundaries of their analyses and include global environmental issues such as climate change, ozone depletion, acid rain, and trans-boundary water quality.

Much of the collaborative work to address global environmental issues took place initially at the national level as international treaty negotiations called for countries to accept responsibility for mitigation actions, subsequently distributing these responsibilities to lower levels of control. Efforts by city governments and non-governmental organizations such as the international association of Local Governments for Sustainability (ICLEI) tied sustainability efforts to voluntary city-level government action. This focus received a boost, especially in Europe, from the United Nations’ Rio Conference’s Agenda 21 compacts for cities (United Nations, 1992). Action in relation to these global issues during this time period increasingly focused on small-scale activities of the consumer, the community, and the city.

Two factors became increasingly relevant in determining cities’ obligations to sustainability efforts: periodicity and geographic scale. Periodicity is an important element of sustainable planning, and a central question of sustainability (one that remains largely unresolved today) involves how to balance

current and future interests. The most commonly cited definition of sustainable development comes from the 1987 United Nations Bruntland Commission Report, *Our Common Future*. It explicitly defines sustainability in terms of benefits spread between current and future generations: “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (World Commission on Environment and Development, 1987). The question of intra-generational equity began to receive significant attention during the late 1990s (Hawken et al., 2000; McDonough and Braungart, 2002).

The geographic boundary of city-level efforts complicates the issue of assigning responsibility for regional and global problems. The *Oxford English Dictionary*’s definition of a sustainable city reflects the complex relationship between a city’s economy and its external effects: “a city designed or landscaped in such a way as to ensure the continued conservation of natural resources and the surrounding natural environment while providing the economic base needed to support its inhabitants” (*Oxford English Dictionary*, n.d.). This definition indicates that sustainability at the city level is related to the environmental quality of surrounding areas but focuses on only local economic growth; however, no consensus yet exists regarding the appropriate boundary of city efforts to enhance economic or social goods. Often, this boundary is set at the scale at which a governmental entity has broad control over the basic subparts of sustainability – water provision and water quality regulation, air quality regulation, waste collection and treatment, transportation planning and infrastructure maintenance, and the provision of social services.

Regardless of where a city’s boundary is drawn, sustainability theory is premised on the idea that environmental, economic, and social disruptions are inherently interconnected and must be dealt with concurrently. In 1996, Maclaren summarized the key characteristics of urban sustainability that are mentioned in the literature: ensuring intergenerational and intra-generational equity (including social equity, geographical equity, and equity in governance); protecting the natural environment; living within the environment’s carrying capacity; minimizing use of nonrenewable resources; and promoting economic vitality and diversity, community self-reliance, individual well-being, and satisfaction of basic human needs. Maclaren also noted that “there is considerable debate within the academic community, planning agencies, and other organizations over the relative importance of each of these . . . characteristics.” Despite the debate, it is clear that this time period saw a renewed emphasis on the social aspects of development, and sustainable city planning during this period is increasingly oriented toward concurrently resolving environmental and social problems, both in the present and for future generations, at the lowest level of governance at which several necessary component actions of sustainability policy can be controlled.

3.2. City-level sustainable development in Europe and the “natural step” system

Europe, especially continental Europe, has been a strong leader in the development of sustainable city plans since the 1992 Rio Summit. In 1990, the European Community published the *Green Paper on the*

Urban Environment and in 1994 developed the Sustainable Cities and Towns campaign, a European-Union-funded informal network of European communities pursuing sustainability (CEC, 1990; Beatley, 2003). Europe's post-war suburban development followed a similar pattern to that in United States, with housing, industry, commercial areas, and green spaces segregated and linked only by extensive rail and road networks (although European suburbs are significantly less spread out than American suburbs) (Basiago, 1996). Despite the opportunities for redevelopment, however, many inner cities in Europe contained the same blighted industrial properties found in other developed countries. These areas became the focus of Europe's efforts. The *Green Paper* called for programs to reintegrate cities and reduce sprawl by creating mixed-use land use coding regimes, increasing residential spaces near job centers, reusing abandoned industrial lands, favoring pedestrian travel, introducing market measures to control automobiles, and other similar strategies. These goals were explicitly tied to regional and global environmental problems; the *Green Paper* (CEC, 1990) focused on the fact that cities were the locus of the majority of air and water pollution sources and that proactive city planning is crucial to determining future energy, waste, water, and transport needs. Europe's urban sustainability efforts got a significant boost from the creation of the Agenda 21 protocols at the Earth Summit in 1992 and the signing of local Agenda 21 voluntary agreements by many European cities and towns (Beatley, 2003; James and Lahti, 2004).

By the time many countries had started to push cities to sign agreements under Agenda 21, Swedish cities had already stepped ahead of the pack. Since the mid-20th century Stockholm had used a transit and pedestrian-oriented growth strategy to cope with urban migration. Building on Stockholm's successes, the "Natural Step" school of thought arose in Sweden during the late 1980s. Using biological principles and expert guidance from scientists, a team of researchers published the Natural Step framework for sustainability and disseminated it to every household and school in Sweden in 1989 (James and Lahti, 2004). This set of fundamental principles expands on the broad formulations of city sustainability that had arisen internationally during the 1980s. Natural Step sustainable community planning is based in part on concern about resource limitations, so cities are pushed to develop programs to reduce the extraction of materials and substances in addition to reducing the concentrations of harmful chemicals and other materials synthesized from nature, reducing environmental damage to eco-system goods, and emphasizing locally sourced products with a difference in priority between essential and luxury goods (James and Lahti, 2004). After the first "eco-municipality" (*eko-kommuner*) was created based on Natural Step principles in the early 1980s, more than 60 "eco-municipalities" were developed in Swedish towns and cities. Initial experiments in a small handful of towns were extremely successful, and their influence grew during the early 1990s both within Sweden and in Norway, Denmark, and Finland where eco-communities were also developed. As a result of the success of the Natural Step philosophy, Sweden has been a leader in sustainable city planning and in the European embrace of Agenda 21. As the Part III case study on Stockholm attests, Swedish developments are outstanding examples of resource conservation and the cycling of wastes but are less effective in addressing the social issues facing many inner city communities in the United States and United Kingdom.

3.3. Japan's eco-communities

After opening to the west, Japan quickly developed an urban redevelopment strategy for the rebuilding effort after World War II. This strategy focused on transit connectivity and waste reduction. Especially during the early 1970s, Japan began regulatory efforts to reduce sprawl, increase city density, plan cities comprehensively, plan for integrated regional waste and transportation infrastructure improvements, and control urban water and air pollution. Environmental concerns arose from high-speed, unregulated industrial development and resulted in the development of a strong popular environmental consciousness that greatly influenced city planning from the 1970s. Many of these efforts were supported by Japan's rail companies, which owned land on the suburban periphery. This resulted in the development of garden suburbs that, like those developed in the United Kingdom and the United States, lacked commercial activity.

After the technology-led growth of the 1980s, the Japanese central government during the late 1990s developed tools, regulatory structures, and programs to support large-scale urban sustainability programs and coordinate local government initiatives (ALMEC Corporation, 2011). A key feature of these developments that has influenced recent eco-city theory is the use of the national government programs as key information conduits for city best practices. Japan's urban sustainability policies currently focus on comprehensive plans developed by local governments (required under Japanese law since the 1990s). Three central-government activities are the Eco-model Program initiated by the Cabinet office; the Eco-town Program initiated by the Ministry of the Environment (MOE) and the Ministry of Economy, Trade, and Industry (METI); and the Guidance for Low-Carbon City Development formulated by the Ministry of Land, Infrastructure, Transport, and Tourism.

METI and MOE began the Eco-town Program in 1997, focusing on public-private partnerships among industry, government, and local residents to enable industrial firms to share and reuse their wastes. Eco-town plans are formulated by local authorities with assistance from the central government and are evaluated by METI and MOE for originality and applicability to other cities. Once plans are approved and certified, the central government gives significant financial assistance for technology application and research and development efforts, as well as for developing policies and disseminating information. As of 2008, METI and MOE had certified 26 eco-towns (ALMEC Corporation, 2011).

The Eco-model Project was started by the Japanese Cabinet Office in 2008 to identify best practices among leading cities for cross-sector low-carbon planning and to apply these practices to pilot cities and eventually to cities nationwide. Thirteen model cities were selected. The national government assisted in developing detailed action plans with sector-specific targets for reducing carbon dioxide (CO₂) emissions, devising program implementation schedules, and formulating evaluation frameworks to predict the CO₂ emissions reduction of each activity. Pilot areas ranged from multi-million-inhabitant cities like Yokohama to individual city districts like Chiyoda-ku in Tokyo. To expand this program, the government formed the Committee to Promote Low-Carbon Cities, which includes 169 entities, including 85 city authorities, 46 prefectural governments, 12 central government ministries, and 25 government organizations (ALMEC Corporation, 2011).

The Japanese government's *Guidance for Low-Carbon City Development*, prepared in 2011, gives local governments tools and strategies to reduce carbon emissions from transportation and urban land-use planning (with a focus on public-transportation-oriented, compact city planning), reform energy production, reuse municipal and industrial wastes, promote energy-efficient buildings, create area-wide energy management systems, improve green urban areas, and reduce heat-island effects. The guidance describes technology and management strategies and gives a standardized approach for estimating the impact of each action on reducing CO₂ emissions (ALMEC Corporation, 2011).

3.4. The sustainable city and national social health in the United States

The sustainability movement began as the conditions that led to global environmental disruptions worsened in the United States. As a result of the continuing suburban exodus that began in the mid-20th century, eight of the 10 largest U.S. cities lost population despite national population growth. By the mid-1990s, more than 60% of U.S. urban dwellers lived in suburban areas, and 40% of the nation's poor were concentrated in inner cities (Beatley and Manning, 1997). The pace of de-densification appears to have accelerated in the 1980s and 1990s as suburbs grew further and further away from city cores (Kahn, 2006). For example, the population of Los Angeles expanded by 45% during this period, but the developed area of the city expanded by nearly 300% (Beatley and Manning, 1997). Similarly, Chicago experienced a population increase of only 1% while the city expanded geographically by 24% (Calthorpe, 2011).

In addition to real economic and environmental effects, de-densification entails social changes at local and higher levels. Suburban dwellers became more atomistic, expressed in the rise of what is referred to as "Not in my backyard" or "NIMBY" responses to social issues, growth restriction regulations in high-class suburban communities, and self-isolation of suburban dwellers in gated communities. Suburban designers refer to this as the "forting up" phenomenon (Beatley and Manning, 1997). Concurrently, in cities the links between social justice and environmental issues became stronger during the late 1980s as working-class and minority communities pressed their rights to equal environmental quality, mounting legal challenges against the siting of trash incinerators, polluting industries, landfills, and power plants in their communities (Wheeler and Beatley, 2004).

The rise of these societal and economic values was critical in the further development of the field of sustainability. As Campbell (2003) states succinctly, if crises can be thought of as the inability of a system to self-replicate or reproduce, then sustainability is the opposite. A society cannot self-replicate without proper management and integration of capital and human social well-being. At the same time, different societies have different social and economic priorities. Self-replication is impossible if subgroups of a society cannot work in harmony, especially if social equity dramatically decreases for a large proportion of the population. Measures of income inequality such as the Gini Coefficient and other measures of social disparities were increasingly used during this period to quantify social disparities.

Despite calls for increased equity, the literature in this period also explores the possibility that different solutions must be pursued for different communities. In contrast to the holistic visions of the garden city, suburban atomization drove the separation of sustainable urban planning into two relatively distinct movements during this period: the development of sustainable neighborhood solutions for the suburbs and the continued effort to find solutions for inner-city environments.

3.5. New Urbanism in the United States and public transit-oriented city planning for the suburbs

During the 1990s, urban design researchers in the United States formed what is known as the New Urbanist movement. New Urbanism focuses on “transit-oriented development”: high-density suburban areas with walkable amenities, close to transit stations, to form hubs of service for residents of existing suburban developments. Similar to Register’s concept of the eco-city, New Urbanism concentrated on reducing car use to abate air pollution and relieve the social effects of congestion and traffic, reducing land use per person through densification, and decreasing crime and the negative psychological effects of suburban isolation (Basiago, 1996). Calthorpe (1993) described balanced, mixed-use areas that meet these goals: they are located within one mile of a light rail station, with multi-use units vertically stacked in condominium and four-story structures, incorporated into the existing suburban fabric. Calthorpe’s plan for the Laguna West neighborhood in Sacramento embodies many of these principles: streets run radially from a dense city center. Residents live in walkable neighborhoods, and amenities are positioned around a central transportation hub (Basiago, 1996).

3.6. Inner-city sustainability

Central cities were economically, socially, and environmentally in disrepair during this period. Until the 1970s, urban renewal largely meant clearing slums and developing high-rise apartment buildings to house the urban poor in the United States, United Kingdom, and other places in Europe. Rehousing was often an afterthought, and inner city residents who were unable to move to the suburbs were increasingly cramped in poor-quality, crowded buildings (Hall, 2002). These financially unsuccessful projects were the scene of riots during the 1970s and 1980s; as a result, major efforts were made to connect local communities with planners. Community engagement was the hallmark of United States policy, and cities were directed to establish Community Development Agencies to mediate between local governments and residents; however, this effort was largely unsuccessful in mitigating the faults of centralized planning, and many redeveloped inner-city areas continue to be problematic today (Hall, 2002).

The 1980s brought a new wave of relatively affluent urbanites back to some inner city areas in the United States and United Kingdom. However, these shifts most often resulted in neighborhood-scale improvements and forced out lower-class residents. The urban poor had been destabilized by the deindustrialization of cities during the 1970s and 1980s as manufacturing increasingly moved elsewhere, and city cores were stripped of jobs and economic activity. Regarding the migration of jobs and

economic activity out of the city, conservative governments in both Europe and the United States believed that over-regulation was preventing the purposeful reuse of vacated sites of economic activity and thus preventing the economic recovery of inner cities. Formerly industrial cities began to experiment with deregulating industrial sites such as port areas to form economic redevelopment zones; however, few of these efforts prevented the continued social disintegration of inner city areas (Hall, 2002).

Although few inner city revitalization efforts succeeded in creating more economically equitable development, a number of new priorities were formulated during this time: ensuring that urban planners and government officials proactively seek out and seriously consider the opinions of socially marginal and disempowered segments of the population; providing low-income housing within each new inner-city development; empowering disenfranchised communities by giving incentives to participate in community development and sustainability efforts; and avoiding directly imposing the unfavorable impacts of development on socially disempowered communities.

3.7. The sustainable city and regional economic sustainability

The Costs of Sprawl and other similar research resulted in the integration of economic impacts in urban planning decision making. Economic sustainability priorities ensure that city infrastructure and services – such as water distribution, public transport, and waste collection – are cost effective, use zoning laws to ensure access to basic economic necessities and services, give tax breaks and other government benefits to local sustainable activities and enterprises such as farmers markets, and increase municipal revenues from activities that enhance sustainability, such as recycling and cogeneration. As computers became ubiquitous during the 1980s and the internet became popular during the 1990s, city governments were increasingly interested in attracting high-tech services to city cores. A key priority of city governments that emerged during the 1980s and continues even stronger today was to attract young, well-educated citizens to power innovative economic activity and work in high-value-added service sectors (Hall, 2002).

3.8. Does an eco-city differ from sustainability theory?

As mentioned earlier, perhaps the most notable scholar of the eco-city is Richard Register. Register's 1987 book *Ecocity Berkeley* as well as his later works summarize his ideas of incremental change in existing cities as well as ambitious plans to build or rebuild new urban communities. This body of work does not differ significantly from the considerable research on urban sustainability. A central goal of Register and others who developed their ideas after the oil crises of the 1970s is to greatly constrain automobile use in cities, reduce direct and indirect environmental and health impacts of personal-transportation-based lifestyles, better integrate cities with local ecological processes, improve the aesthetics of cities, and increase livability and a sense of community by making cities more compact. Register's group Ecocity Builders currently defines an eco-city as "a human settlement modeled on the self-sustaining resilient structure and function of natural ecosystems... provid[ing] healthy abundance to its inhabitants without consuming more renewable resources than it replaces in its bioregion;

function[ing] without producing more waste than it can assimilate or recycle for new uses or than nature can dilute and absorb harmlessly and without being toxic to itself or neighboring ecosystems. [Eco-city] inhabitants' ecological impacts reflect planetary fundamental principles of fairness, justice, reasonable equity and consensus at ample levels of happiness" (Ecocity Builders, 2010).

4. Climate-change-resilient cities in the 2000s

During the 2000s, attention has expanded from planning cities with a goal of inducing ecosystem, economic, and social health to planning for city resilience to ecological and natural resource perturbations. Research during the past five years has increasingly focused on how urban environments can be not only ecologically sound and socially optimal but can adapt to a changing global climate. Notable recent works on this topic include Newman, et al.'s *Resilient Cities* (2009) and the World Bank's *Climate Resilient Cities: A Primer on Reducing Vulnerability to Disasters* (Newman and Jennings, 2008; Prasad et al., 2009). This research concentrates on planning and policy options for cities to counteract the short-term effects of diminishing fossil fuel availability while remaining flexible enough to adapt to longer-term climate change. Other writers who have similarly prioritized the creation of regenerative urban systems include Van Der Ryn and Calthorpe (2008), Hester (2006), and Hopkins (2008).

Resilience is defined as "the capacity of a system to absorb disturbance and still retain its basic function and structure" (Newman et al., 2009). According to Betancourth (2011), a city's resilience measurement, "needs to be applied to all the natural resources on which cities rely," and a resilient city has many centers – local and unique neighborhoods that are semi- or fully self-reliant for energy generation, water, and food production. Indeed, some propose that, with proper planning, cities can become safe havens for the world's populations as climate change effects worsen (Betancourth, 2011). Clearly, these new theories share much with the earlier theories of eco- and sustainable cities. However, these new theories have not been universally adopted. As explored in Part II of this paper, international sustainable and eco-city indicator systems have not yet widely adopted measures of ecosystem resilience.

5. Shift towards smart cities? (~2008–on)

Another recent trend is the expansion of the quantitative assessments of cities that began in the mid-century to use real-time data to dynamically manage cities.

Technology has played an important, if not controlling, role in the theories described above. The advent of Internet communication technologies has also contributed to the rise of a new discipline of large-scale data analysis to aid in city planning efforts. The recent work of scholars at the Harvard Business School may indicate a new addition to the eco- or sustainable city concept: reliance on "smart infrastructure to constantly monitor activity and reduce variations and market failures due to irrational consumer and occupant behaviors" (Alusi et al., 2011). The Alusi report examines eight new eco-city projects and finds the majority (especially those planned in very recent years) rely on smart, centrally operated infrastructure and ubiquitous sensor networks. Many large information technology companies are planning for the opening of the "smart infrastructure" market to allow cities to realize efficiency-related savings unavailable with analog or non-networked traditional systems (Alusi et al., 2011). This focus on maximizing savings through technological enhancement is also noted in Joss's review of eco-

cities (2010). This new concentration on development and implementation of whole-city management platforms may signal a move toward measuring and evaluating city performance using unified and standardized data platforms.

6. Measuring the eco-city – design principles to performance criteria

A phenomenon that characterizes a period that spans several of the modern stages of eco-city planning described above is the movement away from architecture-like design principles and rules of thumb towards the use of indicator systems to allow design flexibility so long as targets are achieved. Based both on aesthetic principles that periodically create architectural schools and the findings of research such as McHarg's and Wolman's, several urban planners since the late 1970s have attempted to develop design principles to guide the development of sustainable cities. These principles were often stated exceedingly generally, and less often gave indications of the scale or time period at which they were to be applied, whom they applied to, whether mitigating factors existed for certain geography or climate regions, or how to prioritize between principles. Indeed, theorists often did not give indicators or means of measuring whether a city successfully adhered to these principles (Van der Ryn and Cowan, 1996; Roseland, 1997).

In addition, the use of a biological analogy to symbolically represent the internal workings of a design principles system also became a common feature in the eco-city urban planning literature. Many sustainable and eco-city design principles are based on abstractions of natural phenomena or processes that do not lend themselves to development of quantifiable metrics. For example, Holmgren's design principles for permaculture communities organize strategies into a flower (Holmgren, 2002), and Register (2006) conceptualizes the city as an organism, describing architectural infrastructure as a skeletal system; engines, motors, and pumps as the muscular system; and so on. Although the United Nations 1990 concept of sustainable development is not explicitly based on a natural metaphor, it is tied to the ten Melbourne Principles for Sustainable Cities and thus similarly unquantifiable (UNEP, 2002).

Appendix A gives examples of design principles from this period. These distinctly qualitative concepts are rarely critically analyzed in terms of the appropriateness of the natural analogies to the actual physical performance of city systems and less often are these systems criticized for their near-complete lack of quantifiable terms. Although planners may look to these works for inspiration, this research suggests that these design principle-based theories offer little benefit to the task of measuring eco-cities in China.

However, during the 1990s and continuing into the 2000s, the number of quantitative studies of cities dramatically increased (Kennedy et al., 2007). Some of these early quantitative studies used statistical analyses to link the characteristics of sprawl-type land use patterns and increased automobile use, giving ammunition to local-level advocates who were attempting to divert highway and road maintenance funding and resources towards building better public transit systems (Newman and Kenworthy, 1989, 1999). The 1990s also saw the growth of material-flow analysis methods and their application to cities (Kennedy et al., 2011). Although the majority of these studies, which have their roots in Wolman's urban

metabolism methodology, were not undertaken to improve urban planning but rather as “accounting exercises” to study energy and resource availability and use (Kennedy et al., 2011), they nonetheless added to the growing body of quantitative urban assessments. By quantifying the drivers of urban environmental change, these studies inspired the development of indicators of cities’ greenhouse gas (GHG) emissions and other environmental impacts.

Sustainable city researchers during the 1990s began advocating for incorporation of traditional sociological variables into studies that exclusively quantified physical states. A good example of this is the *State of the Environment* reports by Newman developed for the Australian government, which include indicators of health, employment, income, education, housing, leisure, and community activities (Newman et al., 1996; Newman, 1999; DSWEPC, 2006). Another development during this time was inclusion of indicators such as water in aquifers serving urban areas, heat stored in rooftops and pavement, and nutrients deposited in soils and waste sites. These indicators added detail to the flow-based evaluations that were common in earlier research (Kennedy et al., 2007). Several computer-based mathematical models were also developed to analyze elements of urban metabolism, such as metals and nutrients (Kennedy, et al., 2011).

The movement from the principles-based approach of the design-oriented urban planning theorists towards the variables and metrics of the quantitative urban analysts is still occurring today. Urban planners and policy analysts during the mid-1990s started to collaborate on concurrently developing principles to guide sustainability planning processes and quantitative metrics to track the sustainability of cities (Innes and Booher, 2000). City-level indicator systems have been developed since the mid-1990s, and there has been a dramatic increase in the number of these systems during the past 10 years. Many entities have developed such systems, including international non-governmental organizations, national governments, local governments, private corporations, and for-profit think tanks. Part II of this report analyzes 16 sustainable, green, and eco-city indicator systems.

Many systems rank cities based on performance in categories that align with the qualitative principles and quantified relationships described previous studies. However, as the analysis in the next section shows, there are several important, unanswered questions about measuring a city’s progress toward sustainability and about ranking cities against each other. Indicators are sometimes chosen according to the types of data that are available, and many types of data are missing. Furthermore, because of important differences in characteristics of cities and the variety of external forces that might affect their performance, no study directly ties performance on any one indicator to improvements in a city’s long-term sustainability. The metrics for evaluating the sustainability of cities are continuing to evolve, as often as annually, and there is little international consensus about the value of specific indicators for measuring long-term outcomes of urban planning decisions. The method described in Part II does, however, help to identify the indicator categories that are most commonly used.

7. Conclusions

Since Howard's works on garden cities in the late 1800s, design-based urban planners have proposed many optimistic visions of utopian communities. By contrast, material-flow analysis applied to city systems starts from a more pessimistic set of assumptions, focusing on detrimental effects of urbanism and physical and natural resource constraints to improving cities. Both perspectives have played important roles in the growth of eco- and sustainable city theory, and both idealism and pragmatism continue to inform city improvement efforts today.

In pursuing the development of low-carbon eco-cities, China has placed itself within an international movement addressing the impacts of urban communities on the local and global environment as well as on social and economic health. Cities drive local and global environmental problems and are also often the sources of technological and policy solutions to those problems. In addition, cities are dominant sources of global economic development as well as the locations of stark differences in social equality. Standard practice in developed countries is to evaluate the sustainability of cities using indicators and systems that measure environmental, social, and economic health. China can draw inspiration from these systems as well as understand their limitations through the several failed ventures in urban planning in post-industrial communities in the west.

An important insight emerging from our literature review is that the physical manifestations of cultural preferences (for example, the desire for large, individually controlled spaces and personal transportation freedom in the United States) and the growing consciousness of the magnitude of human impacts on the environment have influenced the principles and indicators used to plan and evaluate cities. As our understanding of the environmental harm caused by human activity has expanded, and as urban areas play an increasingly important economic and social role, our perception of the quality of cities and surrounding areas has also changed. Urban centers are already exerting a strong force on the Chinese people, and Chinese suburban areas are becoming more sprawling as increasingly wealthy urbanites move to peri-urban and suburban areas. This internal migration puts pressure on the infrastructure and livability of inner-city areas. Unchecked and unplanned urbanization in China could result in growth trajectories similar to those experienced in the United States and Europe where middle-class families left urban cores to find larger personal spaces and better environments on the fringes of cities, and the resulting structural change gutted city cores of economic opportunities. Most importantly, the specter of environmental change looms large over all development efforts and sound environmental management, resource conservation, waste reuse, and revitalization efforts must be strong priorities in China's urban development.

The eco-city and similar theories developed during the past 100 years reflect the dominant environmental and social priorities of their time. As the understanding of human impacts on the environment has matured, and certain drivers of environmental damage have become clearer, urban planning has incorporated more and more variables. The modern authors reviewed in Part I of this report generally agree that improving environmental quality alone is not sufficient for a city to become an eco-, sustainable, or green city. However the questions of how to measure non-physical variables

such as social equity or “green” economic activity remain largely unanswered, and use of social and economic indicators is likely to be driven by cultural factors, just as the early understanding of cities’ environmental impacts was. China, therefore, has considerable room to experiment in using social and economic quality measurement frameworks and should do so both by supporting independent analytical efforts as well as by developing and applying standardized methods to measure social and economic phenomena.

One of the most important questions regards the degree to which local communities need to be integrated into sustainable city planning. The fact that local communities were not involved with planning the failed inner-city redevelopment and slum clearance efforts in the United States and United Kingdom has been used by community participation advocates as proof that community involvement is crucial, but this point is not empirically proven. Rather, this perspective appears to have been engendered by the democratic character of these developed countries (Newman and Jennings, 2008). Sustainable cities literature universally advocates increased public participation but does not present evidence that this prescription produces specific results. Recent quantitative analyses of current eco-city or similar projects in developed countries indicates that the public participation advocated for in much of the western literature is neither a necessary nor sufficient condition for at least early successes in the design, financing, or initial construction of eco-cities (Joss, 2010; Alussi, 2011). Over the long term, however, it appears logical that if cities are to be sustainable, they must be livable for a variety of inhabitants, and it seems likely that some means of involving communities in decision making regarding their spaces will promote long-term livability.

Two strategies, although they might not fit perfectly within China’s political, economic, and social context, are universally considered important and should be considered carefully in developing an eco-city evaluation framework for China. The first is that city planning should be founded on a comprehensive and trustworthy survey of local populations, geographic and resource characteristics, and the relationship between the two. Furthermore, modern urban planners almost universally agree on the significant benefits of undertaking comprehensive planning processes as a first step toward improving the environmental performance of cities. An important part of comprehensive planning is giving a select group of planners jurisdiction to partner with and work across all relevant government departments. The literature clearly indicates that considerable waste and resource misallocation can result from planning activities isolated within individual subsectors. Comprehensive city plans should use a systems-based approach, in which municipal practices and policy areas, such as water protection and energy planning, are addressed concurrently.

Part II. Measuring the Eco-, Sustainable, or Green City

Summary of Part II: This section discusses the complex issues associated with city-level indicators and indexes of sustainability, including how to define the units of analysis and goals of indicators and systems; how to aggregate, weight, and normalize indicators; and how to address policy considerations as well as the practicality and utility of an index. Our main finding is that there are no clear best practices for choosing indicators to assess a metropolitan area. As noted in Part I, this type of quantitative measurement of sustainability is a relatively recent development, and the choice of indicators is often experimental and not necessarily based on empirical evidence of the importance of a particular indicator in determining a city's economic development, impact on the environment, or its inhabitants' well-being. There are significant differences in how indicator systems that have been used to compare performance among cities calculate a final comparative score.

We review 16 systems for evaluating eco-cities, sustainable cities, and green cities, concentrating on physical indicators of environmental, economic, and social health. We discuss the importance of each category of indicators, the most common indicators used in each category, and the units of measurement. For each category, we present findings and recommendations.

As the analysis in Part I of this paper shows, eco- or sustainable city theories encompass multiple objectives. At one end of the spectrum are the objectives of improving air, water, and soil quality by reducing the resources and energy consumed in construction, operation, and deconstruction of infrastructure and buildings. At the other end are the objectives of developing social and physical structures that improve inhabitant health, comfort, and personal fulfillment; minimize waste; encourage sustainable livelihoods and/or economic growth; and result in equity and social harmony. There are also many ideas about the policy and planning requirements for eco-cities, which themselves might be taken as indicators of whether or not a city is truly an eco-city.

Several indicator categories might be used to measure a city's attainment of these broad-ranging goals. Numerous national and regional governments, as well as several non-governmental organizations and for-profit firms, have formulated indicator systems. This diversity of indicator systems makes it difficult to identify international best practices. Few indicator systems agree even upon the basic principles used in their design.

This section first describes the basic tenets underlying indicator systems for measuring urban quality and how these tenets are seen in existing city-level indicator systems. We also break the 16 indicator systems down into their constituent categories and identify the most common metrics used in each category.

1. Methodology

In Part I of this report, we found that the concepts of eco-city, sustainable city, green city, and other similar terms cannot be clearly differentiated. Therefore, we conducted a broad search for indicator systems using several terms: “eco-city,” “green city,” “sustainable city,” “low-carbon city,” and “livable city.” These search criteria turned up both indicator systems and meta-studies of such systems. We used the latter to expand our list of candidate systems. Many systems were inadequate because they lacked comprehensive definitions for indicators, lacked explanation of how indicators were chosen, or for other reasons that would prevent a comparative analysis. We chose indicator systems to analyze in this study based on the following criteria:

1. High-level reference to sustainability, green cities, eco-cities, low-carbon, and livability terminology
2. Measurements at the sub-national level
3. Clarity of indicator definitions
4. Clarity of indicator choice criteria and methodology
5. High frequency of references to an indicator system in the reviewed literature

If an indicator system had existed for several years, we chose the most recent version, on the assumption that it would be the most improved version. When a single organization authored multiple systems, we chose only one, as was the case with the Economist Intelligence Unit’s systems (EIU, 2011b). We evaluated a total of 16 local-level systems (1 neighborhood level, 14 city level, and 1 provincial level).

We reviewed summary documents regarding these indicator systems to obtain information on indicator selection criteria, weighting, and benchmarking. Indicators were grouped into eight primary categories: energy and climate; water quality, availability, and wastewater treatment; air quality; waste production and treatment; transportation; economic development and economic health; land use and urban form; and demographics and social health. Indicators within each primary category were analyzed for the frequency with which they appeared in the chosen systems, based on several secondary categories we created.

Table 1 characterizes the indicator systems we reviewed for this analysis. Out of 16 systems reviewed, nine systems ranked comparative performance among cities (ranking systems), and seven used historical performance in the same city to track progress (non-ranking systems). The nine ranking systems included an average of 26 indicators each. The seven non-ranking systems included an average of 45 indicators each.

Table 1. Summary of Indicator Systems Reviewed

Type	Reference	Object of Analysis	Number of Indicators and categories
City Rankings	EIU, 2011b	Asia's 22 largest and most important cities	29, in 8 categories
	PriceWaterhouse Cooper, 2011	Worldwide 26 large cities of financial and political importance	4, in 1 category (only Sustainability category used. Total of 66 in 10 categories)
	Forum for the Future, 2010	United Kingdom's 20 largest cities	11 indicators grouped in 3 categories
	ACF, 2011	Australia's 20 largest cities	15 grouped in 3 categories
	Karlenzig et al., 2007	United States' 50 largest cities	15 in 15 categories
	Corporate Knights, 2011	Canada's 17 overall most populous cities and most populous city in each province	28 in 5 categories
	EU Green Capitals, 2011	Applicant cities in Europe with population >200,000	71* in 10 categories
	MONET, 2009	17 cities in Switzerland	31* in 3 categories
Provincial Rankings	Esty et al., 2011	All Chinese provinces (excluding Hong Kong, Macao SARs, and Taiwan)	33 in 12 categories
Non-ranking City-level	GCI, 2007	Core and secondary indicators of sustainability of urban areas to facilitate sharing of standardized policy among member cities	77, grouped in 20 themes
	ESMAP, 2011	Tool to allow city leaders to benchmark energy efficiency in their cities against energy efficiency in similar cities to determine best practice policies and strategies	28, in 6 categories
	Heine et al., 2006	Indicators chosen to establish a framework and process to improve citizen engagement, community planning, and evidence-based policy making in Victoria state, Australia,	21 in 1 category (only Sustainable Built and Natural Environment category used, out of 75 in 5 categories)
	Sustainable Seattle, n.d.	Indicators to empower Seattle sustainability advocates and practitioners to take effective action independently and together	99* in 22 categories (goals)
	Boston Indicators Project, 2012	Project to democratize access to information, foster informed public discourse, track progress on shared civic goals, and report on change	29* in 1 category (only Sustainability Category used here, out of a total of 185 in 10 categories)
	Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment, 2007	EU Environmental Program priorities regarding climate change, nature and biodiversity, environmental quality and health, sustainable resource use and waste management	45 in 5 categories
	Xiao, et al., 2010	Tool to measure relative performance over time in Chinese cities that have been the focus of sustainable development efforts	18 in 5 categories

Source: authors' compilation

* Indicates that total may differ from official publications because of authors' choice in three instances: 1) when listed data represented two different indicators, and data were evaluated separately, then indicators were split in two; 2) when indicators had been struck by the authors, they were excluded; and 3) when indicator boundaries were unclear, the similar indicators were left separate.

2. The Structural Foundations of Indicator Systems

Maclaren's seminal work (1996) on urban sustainability reporting describes a process for developing an indicator system. The first step is to define the unit of analysis. The second step is to define the goals of the analysis. Subsequent steps involve choosing a conceptual framework for reporting, preparing the list of potential indicators, paring down that list based on issues of practicality and utility, analyzing the results, and presenting those results to the intended target audience(s). This report uses a modified version of Maclaren's framework to analyze the structural components of the indicator systems we reviewed.

2.1. Units of analysis: what is a city?

To evaluate cities' progress toward becoming sustainable, we need to define what constitutes a city so that we analyze consistent administrative units. Internationally, the range of definitions of cities is wide. Cities can be defined by political boundaries. The United Nation's World Urbanization Prospects is an example, defining a city "according to legal/political boundaries and an administratively recognized urban status that is usually characterized by some form of local government" (UN, 2012). Cities can also be defined by land area, population threshold, or the markets that they foster. Often, cities are defined using more than one of these criteria.

Scale is an important criterion for examination of cities in China because China's cities, home to approximately one-tenth of the world's population, are, on average, larger and denser than the American and European cities that are the subject of traditional eco- and sustainable city theory. In 2005, China had 858 cities with populations greater than 500,000 (Xiao et al. 2009). Tanguay et al.'s review of sustainable city indicator systems (2009) found that metropolitan sustainability indicator systems used a variety of boundaries; the 11 multi-city indicator systems that we examined ranged in the populations they considered, with one incorporating all cities of more than 5,000 persons in a French province and another excluding any British city of fewer than 300,000 people.

As can be seen in Table 1, many ranking systems use a top-down analysis to determine the population of applicable cities. These systems most commonly prioritize the largest cities, by population, of a country or region. However, the determination of a city's population is inseparable from the determination of its physical boundaries. As a result, the international indicator systems reviewed here commonly classify and include cities based on population *and* official designation of boundaries. Several studies included the largest cities in a country, as ranked by population within the statutorily defined city area (ACF, 2011; Forum for the Future, 2010; Karlenzig et al., 2006). Europe's Green Capitals program sets the minimum size for applicant cities at 200,000 inhabitants (Berrini and Bono, 2011). Other studies used several criteria to select cities, including expert opinion regarding economic importance to regional economies (EIU 2009, 2010, 2011a; PriceWaterhouseCooper, 2011). Some studies appear to allow cities to self-report their size, population, and other potential boundary markers (ESMAP, 2011; GCI, 2008; Berrini and Bono, 2011).

China defines cities based on political and administrative jurisdictions. There are three official urban administrative types in China: 1) provincial-level municipalities; 2) prefecture-level cities (PLCs); and 3) county-level cities (CLCs). There are four provincial-level municipalities: Beijing, Shanghai, Chongqing, and Tianjin. These cities are given status and administrative powers nearly equal to those of provinces. PLCs are generally smaller in size and report to provincial governments. CLCs are county administrative seats that meet statutory benchmarks to qualify as cities under the State Council and report to PLCs (although statutory control has gradually shifted to CLCs and county governments). A key distinguishing factor between PLCs and CLCs is that city sub-districts are allowed in PLCs, creating a two-tiered administrative structure in those areas, whereas CLCs are single-tier administrations without sub-districts. Figure 2 is a simplified diagram of the subparts of Chinese CLCs (top) and PLCs (bottom) and their relationship to outlying areas that are outside direct city oversight (shades of gray).

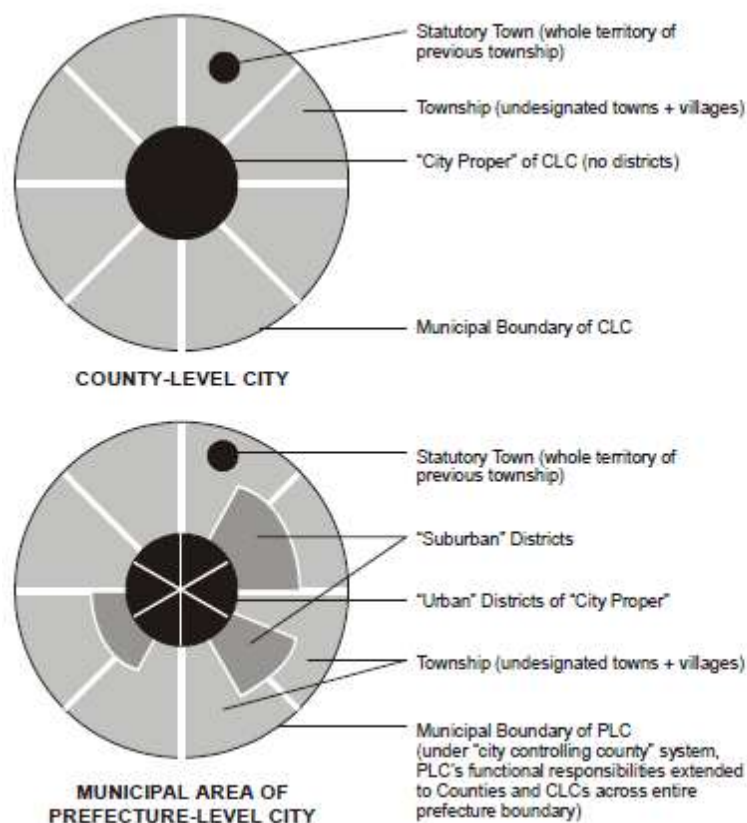


Figure 2. Statutory Urban Areas in China

Source: Kamal-Chaoui et al., 2009.

China's most recent official guidance on the statutory designation of cities was released in 1993. Although slight changes were made in 2000, there has, since 1996, been a "*de facto* moratorium on further urban reclassification" (Kamal-Chaoui et al., 2009). As shown in Table 2, Chinese cities are

defined based on a number of factors, including population, economic structure, public finance, and infrastructure availability.

Table 2. Factors Determining Chinese City Type

Benchmark Category	Benchmark Definition	Benchmark
Population	Household registration: non-agricultural population	PLCs: > 205,000 CLCs: >100,000 (+ non-farming population of at least 150,000)
Economic	Tertiary share of gross domestic product (GDP)	CLCs: >20% PLCs > 30%
	Size of GDP (rural + urban)	CLCs > 600 million Renminbi (RMB) PLCs: >2.5 billion RMB
	Gross value of industrial output	CLCs: > 800 million RMB
	Gross value of industrial output as a share of gross value of industrial and agricultural output	PLCs: > 80%
Public finance	Revenue (not defined as on or off-budget; no stated adjustments for inflation)	CLCs: > 40 million RMB PLCs > 150 million
Infrastructure	Tapwater coverage rate (to non-agriculture regional populations)	CLCs: >55% PLCs: >50%
	“Proper” roads coverage (to non-agriculture population)	CLCs: >55% PLCs: >50%

Source: Kamal-Chaoui et al., 2009⁴

China has 663 official cities, including 283 PLCs and 370 CLCs (NBS, 2011). The National Bureau of Statistics has issued guidance on the classification of rural and urban areas based on population densities as well as location in relationship to urban infrastructure and public services. These classifications are used to calculate urbanization rates (Kamal-Chaoui et al., 2009). There is also the possibility of categorizing cities as urban areas or prefecture areas. Urban areas (called *shiqu* – loosely translated as the “city proper” or “urban district”) includes both *chengqu* (the built-up area) and *jiaoqu* (suburban areas) but does not include surrounding counties and CLCs under the city’s jurisdiction (Fan, 1999). A broader term, *diqu* (prefecture area), includes all areas under a city’s administrative jurisdiction. To exclude areas beyond those that are actually urbanized and under the direct control of city governance, most researchers studying cities in China limit city boundaries to *shiqu* (Fan, 1999).

In addition to using city size to determine the population of cities to be compared in a ranking system, the EIU subcategorizes cities by several characteristics. To mitigate the effects of differing urban scope, scale, climatic, and historical characteristics, the EIU studies of green cities in Latin America, Europe, and

4 Kamal-Chaoui et al. (2009) note several limitations to the above benchmarks: 1) The population base used in calculations excludes migrants and those lacking urban hukou (China’s city residency permits). 2) Assessments of urban economic functions are imprecise; for example, GDP figures are used, which include agriculture, mining, and forestry. 3) Assessments of fiscal capacity are incomplete because off-budget revenues are not measured. 4) Arbitrary benchmarks are used for infrastructure endowments that have weak functional links to either urban economic activity or actual residents’ demands for urban infrastructure services.

Asia group cities by population, area, income, density and temperature (EIU 2009, 2010, 2011a, 2011b). Table 3 gives an indication of how the EIU clustered 24 Asian cities for comparison.

Table 3. Examples of Variables for Cluster Analysis

Cluster variable	Low	Medium	High
Population (citizens)	Less than 5 million	5-10 million	More than 10 million
Area (square kilometer [km ²])	<1,000 km ²	1,000-5,000 km ²	>5,000 km ²
Income (GDP per capita)	<US\$10,000	US\$10,000-US\$25,000	>US\$25,000
Density (citizens/km ²)	<5,000	5,000-10,000	>5,000
Temperature (average temp °C)	>16°C	16-25 °C	>25°C

Source: EIU, 2011b.⁵

The EIU Green City indicator system is a unified means to evaluate and rank all major cities in a region and to analyze categories of cities based on characteristics that affect environmental performance but are largely beyond the influence of short-term political action by local officials.

The majority of ranking systems do not evaluate all cities within their geographic scope but rather use either a gross rank of population size or set thresholds to determine the cities to be evaluated. China's existing definitions of cities are a convenient system by which to select cities to rate for their low-carbon eco-city characteristics. PLCs and provincial-level municipalities are generally more populous than their CLC counterparts and are a more important part of provincial economies, so it is likely most appropriate to apply an eco-city indicator system to these two types of cities.⁶

China's cities differ substantially in their performance with regard to several potential sustainability indicators and subdivisions. Therefore, use of indicator analyses normalized for city characteristics such as population, area, and other variables that could determine a city's performance appears to be a promising strategy in China. A nationally relevant indicator system for China should, because of the high degree of variability in city characteristics, conservatively use consistent categories, indicators, and variables and avoid indicators that would apply only to certain geographic areas. To the extent possible, these should match with the best practices of other international city measurement systems so as to create an easily comparable database of world best practices. However, the most important determinant of the final makeup of the indicator system should be China's own domestic policy goals and development trajectory aspirations.

⁵ The thresholds used in the EIU's Asian Cities report are different from the benchmarks used in other EIU Green City reports.

⁶ However, caution is warranted when relying solely on China's official definitions of cities. As Kamal-Chaoui et al. (2009) note, "The boundaries of the vast majority of China's cities were established decades ago. Officially reported data, such as ... population sizes, conform rigidly to these boundaries. With rapid urbanization and the loosening of state-level controls on urban and economic development over the last two decades, large cities – especially metropolitan regions – have grown beyond the boundaries of the 'city proper' to encompass parts of suburban districts that are often not counted in official urban statistics, or to surrounding cities that, by definition, are still considered 'rural.' Statistical reporting is therefore often distorted."

2.2. Use of policy-based indicators

In all of the systems analyzed in this report, the majority of indicators use quantitative metrics to evaluate the eco-city characteristics listed earlier: improvement of air, water, and soil quality by reducing the amount of resources and energy consumed in construction, operation, and deconstruction; and social and physical structures that support the health, comfort, personal fulfillment, and sustainable livelihoods of residents as well as equity, social harmony, and economic growth. Indicator systems also commonly incorporate measurements of policy and planning activities by municipal governments, the presence or absence of which indicates whether the city is moving toward becoming an eco-city. Examples of policy activity indicators include whether the city has established a comprehensive city sustainability plan, a carbon emissions reduction plan, or a drinking water improvement plan.

Evaluating policy indicators is difficult because they do not lend themselves to incremental scales or standardized measurements. One method is a binary evaluation that assesses whether a city does or does not have a certain type of favored policy or program. Some binary policy indicators encompass multiple policy actions. An example of a binary indicator is the SustainLane ranking system, which assesses cities' knowledge base and communications based on the presence or absence of four policy activities: 1) an overall plan for sustainability; 2) an environmental or similar department that manages and tracks sustainability efforts across the city; 3) collaboration with a major federal research laboratory or research university; and 4) working with a non-governmental organization on sustainability projects, programs, or metrics citywide rather than just within a single neighborhood (Karlenzig et al., 2007). The response to each yes-no question is given a $\frac{1}{4}$ multiplier in determining the overall score of the indicator (out of one) for each city. The drawbacks of this binary evaluation system are suggested by the fact that the top ranking in this category was held by 10 cities, all of which achieved full points. Furthermore, there is no means within a binary policy indicator to evaluate relative quality or strength of policies unless the definition of the indicator is very precise. This can result in a city that has a sustainability plan in name only receiving the same score as a city that has been a pioneer in developing and implementing its sustainability plans and programs.

Some qualitative policy indicator systems use an expert review panel to evaluate the strength and quality of policy activities (e.g., EIU 2011b, and Berrini and Bono, 2011). The Asian Green City Index, for example, evaluates the quality of a city's climate change action plans based on an expert panel review, which gives the city a score on a scale of 1 to 10 (EIU, 2011b). This system avoids the imprecision of the binary policy evaluation system described above, but it can also lack transparency, i.e., clear criteria that the expert panel uses to award points.

In the indicator systems reviewed here, evaluation of policy goals was most common in systems established by governments, such as the Swiss MONET system. Other systems, especially those that attempt to rank cities in different countries, rarely referenced policy goals because these are difficult to compare among cities in different nations.

A national indicator system should contain indicators of city performance in relation to national policy goals as long as these goals are within the scope of local government power and fit within broader eco-city goals. National policies are important guides for local governments and there may be significant implementation barriers such as insufficient political capital to enforce programs if nationally prioritized indicators are discarded. Relying on national policy goals as indicators also enhances comparability among cities because all cities will presumably be working toward those goals, which would not be the case for regional or local goals. However, a stronger case can be made for relying on non-national policy goals when international practices are so well supported as to become a ubiquitous feature of international city-level efforts. The C-40 Cities program and others that have allowed cities in many countries to use CO₂ emissions reductions goals set at the international level are good examples of using international instead of national goals. Another example of this is the development of comprehensive sustainability plans. More than half of the 40 largest cities in the United States have developed sustainability plans despite a lack of federal consensus on the issue, and another 20 are currently developing such plans (Woodlaw and Loewen, 2012). Systems that evaluate cities partaking in either activity should include indicators that are scaled to the existing effort at the local level even if that effort goes far beyond any nationally required effort.

Although policy actions are an important determinant of sustainable or eco-city outcomes, evaluating the sustainability of cities based on their policies raises a number of questions. As noted above, all policies are not equal; the fact that a city has a particular policy does not reveal the quality of that policy. Evaluating policies based on expert review is not sufficiently transparent or replicable unless the evaluation method is carefully documented. This report therefore recommends quantitative evaluations whenever possible. If policy indicators are used, binary indicators (determining whether particular types of policies exist in a city) are more transparent than expert-evaluation based policy metrics.

2.3. Indicators versus indices

How is an indicator different from a simple data point? Data become indicators when, through research, we understand the relationship of the data to a larger phenomenon that is being measured and prioritized (Tanguay et al., 2009). In its city indicators project, the World Bank uses the Organization for Economic Cooperation and Development (OECD) definition of an indicator: “A statistic or parameter that, tracked over time, provides information on trends in the condition of a phenomenon and has significance extending beyond that associated with the properties of the statistic itself” (Hoornweg et al., 2007). Maclaren’s definition states that indicators “reflect something basic and fundamental to the long term economic, social or environmental health of a community over generations” (Sustainable Seattle, 1993). Elaborating on this definition, Maclaren (1996) states that indicators are simplifications of complex phenomena, and that a single indicator is seldom able to fully characterize a subject.

Composite indices are combinations of indicators. Examples include Wackernagel and Rees’ ecological footprint or Human Development Index score, which is designed to quantitatively evaluate difficult-to-analyze issues such as social and net resource depletion (Wackernagel and Rees, 1996; UNEP, 1990).

Composite indices are more complex than single-metric indicators, so detailed explanations may be necessary for policymakers and community members to understand their meaning (Best et al., 2008). Furthermore, because of the difficulty of determining city boundaries, indices are often used for larger, e.g., national, areas (Best et al., 2008). Like indicators, indices only show one piece of a complicated story and can have inherent biases. Indices often require indicator system managers to collect data through surveys and to analyze the results using expert panels.

Indices are increasingly favored by some authors (e.g., Kahn, 2006) for evaluating a city's sustainability, and the great majority of systems analyzed in this report used one or more indices. These include indices created especially for use by particular evaluation systems (for example, several variables contained within single indicators in the SustainLane system) and indices developed by other research (for example, the use of ecological footprint calculations in the United Kingdom's Sustainable City Index, see Karlenzig et al. 2007 and Forum for the Future, 2010). A challenge in using indices is that they combine several variables into a single metric, which obscures the importance of each variable; thus, indices are relatively opaque to casual users of evaluation systems.

To ensure transparency and feasibility, this report recommends that indices not be used in China for evaluating cities' sustainability if a category can be sufficiently analyzed using single-variable indicators. However, useful indices might be developed in the future and standardized nationwide, for issues such as resident satisfaction, social harmony, and other less-easily-quantified topics.

2.4. Building an indicator system

The subsections below describe the steps involved in creating an indicator system: defining criteria on which to base the selection of indicators, establishing benchmarks, determining the weight of each indicator, and addressing the verifiability of a system.

2.4.1. Indicator selection criteria

Indicators must be selected based on a predetermined set of criteria. Maclaren recommends that indicators be selected based on the following criteria: scientific validity, representativeness, responsiveness to change, relevance to users' needs, reliance on accurate accessible data/time series data, understandability, comparability with other indicators, cost-effectiveness of collection, attractiveness as headlines, and lack of ambiguity (Maclaren, 1996). When criteria clash – for instance when data are only available for an indicator that is scientifically valid but difficult for the public to understand – Maclaren suggests devising a community-priority weighting scheme for these criteria based on an inclusive stakeholder process. However, as “Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment” (2007) points out, Maclaren's selection criteria are not followed universally, and researchers have noted a substantial lack of selection criteria in the field of environmental sustainability indicators (Niemeijer and de Groot, 2008).

Indicator selection criteria can be categorized into three types: those based on normative principles, those based on relationships among indicators, and those based on constraints such as limits on data collection.

An example of normative selection criteria is the United Nations 10 Bellagio Principles, which are based on normative sustainable development criteria established in the Agenda 21 process. The OECD similarly has its own 11 criteria for environmental indicators based on OECD policies that prioritize economic development (Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment, 2007).

An example of indicator-relationship-based selection criteria is the United Nation's driving force-pressure-impact-state response (DPSIR) system, which selects series of indicators based on causal links among them.

Another example of an indicator selection criterion system that is specifically focused on creating efficient and information rich indicators is the SMART system (Doran, 1981). The SMART criteria are used in business and governance to define contextually-appropriate goals and indicators by which to measure progress towards those goals based on a common problem discussed in agency theory: how to accurately transmit the desires of a principle in a way that can be easily and clearly understood and implemented by agents and that allows outcomes to be evaluated by principles. Each letter of the SMART acronym stands for a key characteristic that enhances the utility of indicators for guiding the activities of agents according to the intentions of principles. The system is gaining acceptance in Japan, Europe, and elsewhere as a simplified means of evaluating policy measurement and verification options, especially indicators (Shen et al., 2011).

Because indicators are intended to be used in making policy, their practicality and utility should be a priority (Hoornweg et al., 2007). An indicator's practicality is determined by whether or not the data exist and can be collected as well as whether the data reflect issues that can be influenced by the government collecting the data or whose performance is being evaluated. Consideration should also be given to agency staffing resources, availability of standardized data across the locality at the scale desired, and availability of consistent funding for data-gathering efforts. An indicator's usefulness has to do with whether it will allow its intended audience to make informed decisions regarding what should be done next to improve the quality of the environmental, social, economic, and/or governance characteristic being measured.

In practice, municipal-level limitations on collecting and using indicators appear to have strong influence. Table 4 shows that there were great differences in how indicators were selected for the systems reviewed in this report. Of the 16 indicator systems reviewed, 12 discussed the criteria used to select their indicators. The relevance of data to local decision makers, the limitations on data gathering, and the comparability of indicators were the most common selection criteria.

Table 4. Indicator Selection Criteria

Indicator Selection Criteria	Commonality of Use
Relevance	6
Data availability	5
Comparability	5
Ease of understanding/accessibility	4
Measurement of phenomena that can be influenced by municipal authorities	3
Measurement of progress toward established policy goals	3
Data quality	2
Currentness of data	2
Use in other index systems	2
Suitability to on-the-ground circumstances	2
Other (18 different criteria)	1

Source: Authors' compilation

Our finding that selection criteria are diverse is consistent with Tanguay et al.'s 2009 finding that 68 different selection criteria were used by 17 indicator systems. The six most common were: credibility, universality, data availability, comprehensibility, links with management, and spatial and temporal scales of applicability. Diversity in selection criteria may be a result of the differing purposes of indicator systems. For example, ranking systems all had data relevance as a central priority, all but one emphasized data comparability, and all but two emphasized data availability. The criteria of non-ranking systems were much more diverse.

The Bellagio principles and OECD indicator selection criteria are based on normative principles of those organizations. Normative principles have not been clearly defined in China. The United Nations' (U.N.) DPSIR and related causal-chain-based selection criteria are favored by some researchers, but this system results in a large number of indicators; in addition, the U.N. has largely dismissed causal-relationship-based indicator selection criteria because they are difficult to find. In contrast to these systems, the SMART system avoids normative selection criteria and the complexities of the DPSIR system and instead uses the most common selection criteria found in the indicator systems reviewed here.

Maclaren's recommendations (1996) for weighting selection criteria based on local needs are instructive. China's municipal data collection capacity varies among cities and is often driven by national statistical collection requirements. Therefore, the availability of data is relatively more important than the timeliness of the data, assuming that data collection regimes are more difficult to establish in the first instance and that the statistical collection system results in approximately equal data timeliness across most cities. Data gathering should be supported through the existing statistical data collection system. Specificity of indicator definitions is important to ensure comparability of data; however, because of national data collection standards, this criterion is less of a priority because standardization of indicator definitions is inevitable in this system. Strong, but not dominant, weighting should be applied to the question of whether indicator data can be collected at the local level. That is, for any indicator that is to be used to evaluate the sustainability of cities and that is not currently collected at the city level, it must be possible to gather the data needed at the city level without a considerable expansion of city

resources. The relevance of indicators to local level eco-city efforts in China should be strongly weighted. Whether city officials can influence the performance of eco-city indicators is limited to some extent by national political forces (for example, provincial and national, rather than city-level, approval of certain infrastructure and industrial projects) as well as national and regional governance of utility services (such as electricity and water). Therefore, the real limitations on city managers' ability to implement indicator improvement strategies should be weighted strongly in choosing indicators as well as refining them in the future as the system matures. Finally, empirical data are lacking that would enable the defining of clear relationships between indicator performance and overall city sustainability or the achievement of eco-city principles. Therefore, McLaren's requirement of scientific validity is not achievable in most cases. Rather, at this point, the best basis for choosing indicators is how commonly used an indicator is in the international community. Although this strategy is imperfect, the authors feel that it enables the identification of indicators that are highly valued by issue experts, that have worked for other communities, and that were formulated with reference to on-the-ground circumstances faced by other communities pursuing sustainability goals.

2.4.2. Benchmarks

Tanguay et al. (2009) propose two possibilities for measuring a city's progress over time: a city's performance can be compared to benchmarks (target values) or to the performance of other cities (relative performance). Benchmarks are absolute values against which indicator performance is measured over the long term, allowing comparison of the change in indicator values over time to performance goals (Rickard et al., 2007).

The global Environmental Performance Index (EPI) system developed by Yale University and applied to China at both the national and provincial levels uses internationally accepted benchmarks to assess performance for several indicators (Emerson et al., 2010; Esty et al., 2011). This system allows the transparent use of threshold values that have often been scientifically validated by correlation to human and environmental health metrics. Although the use of scientifically validated benchmarks is a high priority in the EPI system, they do not exist for all indicators. For example, in Esty's EPI system, 11 of the 24 indicators do not have scientifically established benchmarks. In cases where scientific fact cannot be used to establish a benchmark, Esty et al. use national targets, international norms, and experts' normative opinions (Esty et al., 2011).

Tanguay et al. (2009) state that relative values are "generally used in cases where indicators and indices have no scientifically established thresholds or consensual critical values." Relative values are the most commonly used; the indicator systems analyzed here rarely use benchmark values to evaluate city performance (Moldan and Dahl, 2007).

One means of establishing benchmarks in the absence of a scientifically validated value is to base them on domestic top performers or internationally recognized cities. Several ranking indicator systems reviewed here use a top-performing city to establish performance benchmarks. However, benchmarks based on top-performing cities might not result in appropriate or relevant targets for cities in other countries for two reasons: cities in different political systems can have differing political, economic, and

social capabilities that influence indicator performance, and cities in different political systems might also face significantly different physical conditions that strongly influence outcomes. Therefore, when considering using relative values based on performance of cities in other countries, it is important to analyze the appropriateness and relevance of a benchmark to the particular country or city in question.

Esty et al.'s study (2011) reveals another problem with using benchmarks: the potential for wide variation in performance. To reduce the range of variation, the study rates provinces of China for each particular indicator in a system compared to a reference value (benchmark). Performance is then normalized by setting the policy target at 100, and the performance of the worst-performing (i.e., furthest from the policy target) province at zero. All values between the benchmark and the lowest performer are then ranked on this 0-100 scale, with any area exceeding the policy target given the maximum point allocation, but no more, for that indicator. A logarithmic scale is used to transform data if the placement of cities on the performance spectrum is heavily skewed.

With regard to the priority order for setting benchmarks, the highest priority should be benchmarks based on internationally recognized scientific data that link performance to commonly shared values of sustainable and eco-cities, especially improvements in human health. Given the importance of national policy goals to city-level activities in China, performance relative to national policy goals could be the next-best choice when scientifically valid benchmarks do not exist. If relative values must be used because neither scientifically based benchmarks nor national policy goals are available, performance could be compared to either that of top-performing Chinese cities or top-performing international cities. Both have value, allowing interested policymakers to discover how the top-performing city achieved its results and thus potentially inspiring adoption of similar policies or their adaptation to the Chinese context. A benchmark that is based on the performance of an existing Chinese city might not set the bar high enough for a low-carbon eco-city indicator system, but a benchmark based on international cities might be unrealistic for Chinese cities. The choice of domestic or international cities as benchmarks will therefore require that the average performance of domestic cities for that indicator be analyzed first, to determine whether domestic best-performers are sufficiently better than the average value to be used as benchmarks. When average international values are substantially better than domestic top performers but do not differ much from average Chinese city performance levels, benchmarks should be set based on international top-performing cities. In addition, international benchmarks should be favored if performance levels of Chinese cities cannot be evaluated because of lack of data. Because best-performing cities may differ significantly from average cities, we recommend Esty et al.'s methods for scaling performance based on proximity to benchmarks for a low-carbon eco-city indicator system for China. We also recommend the use of logarithmic scales for skewed data (Esty et al., 2011).

2.4.3. Weighting of indicators

Indicators are sometimes weighted if performance of individual indicators is aggregated into an overall performance score. Weighting entails attributing multiplier effects to one indicator relative to another so that the weighted indicators have greater impact in determining overall ranking. Indicator weighting is especially relevant for systems that are established based on a variety of policy goals that are of unequal importance.

Weighting can be accomplished in two ways: indicators can be purposely weighted to reflect policy priorities, or categorization schemes used in indicator systems can establish implicit weights. The Asia Green Cities Index is an example of implicit weighting (EIU, 2011b). In that system, indicators are grouped into eight categories. The total score is an aggregate of the subtotals of the eight equally weighted category scores. Indicators within each category have the same weight as the other indicators in the same category. For example, in a category with three indicators, each indicator weighs 1/3 of that category's score. However, because categories contain different numbers of indicators, some indicators receive more weight than others in the total aggregated score. For example, an indicator in a category with three indicators would be given a 1/24 weight ($1/3$ of its category * $1/8$ of the total score because there are 8 categories) in the overall ranking whereas an indicator in a category with four indicators would be given a 1/32 ($1/4$ * $1/8$) weight in the overall ranking.

Tanguay et al.'s literature review (2009) reports that many object to weights as arbitrary. In the theoretical literature, the two main arguments against weighting are that it reduces the replicability of the indicator system, and that it is not possible to determine whether an indicator's weight is even approximately proportionate to the effect of that particular indicator on the outcome being evaluated. The first argument assumes that no two groups of professionals working independently within the same policy context would assign the same weighting values to all indicators. Regarding the second argument, it is nearly impossible to prove that a weight is scientifically justified because cities are complex systems and can behave in counterintuitive and confounding ways. Even with an objective measure of city performance in relation to a goal like sustainability – such as human health impacts or total carbon emissions – data limitations often make it impossible to establish weights based on the impact of an indicator. This is especially true for social and economic indicators.

Furthermore, policy and infrastructure changes that might be made in response to one relatively heavily weighted indicator could have the opposite of the intended effect, i.e., they could limit rather than enhance the long-term sustainability of the city. One could imagine such a result if, for example, air pollution emissions were so heavily weighted that the worst emitters decided to filter emissions through water to avoid compromising the city's performance in the air pollution category, and the polluted water was then dumped into local water bodies or underground aquifers whose quality was less heavily weighted as a policy priority even though these water sources are also crucial to city health.

In the nine ranking systems reviewed here, three overtly weighed some indicators more than others, five implicitly gave more weight to some indicators, and only one indicator system directly avoided the use of weighting: the PriceWaterhouseCooper Cities of Opportunity Index gave all indicators equal weighting in determining overall rankings (PriceWaterhouseCooper, 2011).

The implicit weighting scheme, which was the most common, aggregates a total score from indicators that are grouped into categories. Table 5 shows results from the Asian Green Cities Index, which is an example of an implicit weighting scheme.

Table 5. Example of an Implicit Weighting Scheme in the Economic Intelligence Unit's European Green Cities Index

Categories	Indicators	Indicator within ranking	Indicator within whole
CO₂	CO ₂ Emissions	0.33	0.04125
CO₂	CO ₂ Intensity	0.33	0.04125
CO₂	CO ₂ reduction strategy	0.33	0.04125
Energy	Energy Consumption	0.25	0.03125
Energy	Energy Intensity	0.25	0.03125
Energy	Renewable Energy Consumption	0.25	0.03125
Energy	Clean and efficient energy policies	0.25	0.03125
Buildings	Res. Energy consumption	0.33	0.04125
Buildings	Energy efficient building standards	0.33	0.04125
Buildings	Energy efficient building initiatives	0.33	0.04125
Transportation	Use of non-car transport	0.29	0.03625
Transportation	Size of non-car transport network	0.14	0.01750
Transportation	Green transport	0.29	0.03625
Transportation	Congestion reduction policies	0.29	0.03625
Water	Consumption	0.25	0.03125
Water	System leakages	0.25	0.03125
Water	Wastewater Treatment	0.25	0.03125
Water	Water efficiency and treatment policy	0.25	0.03125
Waste and Land	Municipal waste production	0.25	0.03125
Waste and Land	Waste recycling	0.25	0.03125
Waste and Land	Waste reduction and policies	0.25	0.03125
Waste and Land	Green land use policies	0.25	0.03125
Air	Nitrogen dioxide (NO ₂)	0.20	0.02500
Air	Ozone (O ₃)	0.20	0.02500
Air	Particulate matter < 10 microns (PM ₁₀)	0.20	0.02500
Air	Sulfur dioxide (SO ₂)	0.20	0.02500
Air	Clean Air Policies	0.20	0.02500
Governance	Green Action Plan	0.33	0.04125
Governance	Green management	0.33	0.04125
Governance	Public Participation	0.33	0.04125

Source: EIU, 2009.

Explicit weighting was used by three of the nine rating schemes. A good example of an explicit weighting scheme is the SustainLane study (Karlenzig et al., 2007), which gives equal weight to 11 of the 15 indicators and assigns a weight of 1.5 to the “Commute to Work” indicator because of “the direct and indirect impacts on numerous other categories” of personal automobile travel, and a weight of 0.5 to the “Congestion, Affordability, and Natural Disaster Risk” indicators because of their limited importance in the authors’ minds (Karlenzig et al., 2007).

2.4.4. Other issues: verifiability and qualitative metrics

Who owns data and who is responsible for evaluations are important elements of designing a credible rating system. Hoornweg et al. (2006) point out that “A system of indicators controlled and maintained by [a city] in order to monitor their own performance is likely to generate incentives to manipulate the results.” Most systems relied on either data reported directly by the city or on data available in central databases. Few systems discussed the issue of data verifiability, and, when it was discussed, authors most frequently stated that best efforts were made to verify the data and rely on high-quality data sources, but independent verification was outside the project scope.

Furthermore, no set of indicators should be static because measures of city health change with economic growth and technological development. Indicators should be re-evaluated regularly to ensure that they accurately reflect policymakers’ goals. The formal revision process used by the International Standards Organization could be used as a model for the continuous re-evaluation of indicators (Hoornweg et al., 2006).

Related to the issue of whether data are available is the issue of whether bias is introduced in data review. This report found a variety of indicators that cannot be easily measured quantitatively. For example, policy evaluations and indicators of social phenomena (e.g., diversity, public participation, etc.) are very difficult or impossible to measure using traditional scientific tools (Scerri and James, 2010). Although using a group of experts to subjectively evaluate the strength of policy, education, diversity, participation, and similar indicator appears inconsistent with having a replicable, objective system, many indicator systems analyzed for this report use this approach.

3. Key Findings Regarding Indicators and Indicator Categories

We compared in detail 16 indicator systems that measure eco-, sustainable-, and green-city qualities. The subsections below present our findings regarding the degree to which systems have indicators in common as well as our recommendations for each type or category of indicator.

3.1. Frequency of use of specific indicators

There is very little duplication or overlap of indicators among systems. The list below identifies indicators used by more than one system and gives the total number of systems using each.

- Water: Total consumption intensity (liters/capita/time unit); six systems
- Land: Population density (persons/area); six systems
- Air: Annual daily concentrations of particulate matter smaller than 10 microns (PM₁₀) (milligrams/cubic meter[m³]); five systems
- Air: Annual daily mean nitrogen dioxide (NO₂) concentrations (milligrams /m³); five systems
- Energy: Proportion of renewable energy in primary energy; five systems

- Energy: Total CO₂ equivalent (CO₂e) intensity (tonnes/capita/year); five systems
- Land: Green space intensity (area/person); four systems
- Waste: Total waste intensity (kilograms [kg]/capita/year); four systems
- Water: Share of wastewater treated to at least primary level; four systems
- Air: Days per year exceeding benchmarks set by national air quality standards; four systems
- Social: Voting rate; four systems
- Waste: municipal waste intensity (kg/capita/year); three systems
- Economy: Unemployment rate, working age population; three systems
- Waste: Household waste intensity (kg/capita/year); three systems
- Waste: Percentage of municipal solid waste recycled; three systems
- Waste: Percentage of total waste recycled; three systems
- Waste: Percentage of solid waste that goes to landfill; three systems
- Transport: Personal automobiles per capita; three systems
- Transport: Time in traffic (hours per person per year); three systems
- Economy: Employment rate, working age population; three systems
- Social: Percentage of adult population with high school diploma or equivalent; three systems

The majority of these indices do not agree on even a single metric. This is similar to the findings of Tanguay et al. (2009), whose study of 17 municipal indicator systems found that 72% of indicators were used by only one system, and none were used by a majority of the systems. However, it should be noted that our list of shared indicators is considerably shorter than that composed by Tanguay et al., who relied on an abundance of indicators from North American and European systems, which might have been cross-referenced when indicators were chosen. Tanguay et al. also focused on sustainability, whereas our research considered a broader range of terminology.

Our finding that there is little or no overlap among indicators in different systems is similar to findings from other research. For example, the Global City Indicators Facility, a World Bank-associated group creating a sample of best-practice indicators for measuring local level sustainability goals, found that cities collect, on average, more than 100 indicators for their own indicator systems. Although more than 1,000 indicators were being collected in the eight pilot cities examined by the project, only three indicators were common to all cities (GCI, 2008).⁷

3.2. Findings: Indicator Categories

The subsections below describe the degree to which indicator categories as well as specific indicators in each primary category appear in different systems. We summarize the patterns and missing elements we observed and describe the potential application of our findings to the Chinese context.

⁷ Pilot cities/counties are Belo Horizonte, Brazil; Bogotá, Colombia; Cali, Colombia; Montreal, Canada; Puerto Alegre, Brazil; Sao Paulo, Brazil; Toronto, Canada; Vancouver, Canada; and King County, Washington, U.S.A.

3.2.1. Energy and climate

3.2.1.1. Commonality of indicators

All 16 systems that we evaluated had at least one energy or climate indicator although not necessarily both. The total number of energy and climate indicators within an individual indicator system ranged from one to 15. Between 5% and 54% of the total number of indicators in a system addressed energy and carbon issues. The average was 17%.

Indicators found within more than one system were as listed below, including the number of systems within which each was found:

- Proportion of renewable energy in primary energy; five systems
- Total CO₂e intensity (tonnes/capita/year); five systems
- Primary energy consumption per capita; two systems
- Electricity consumption per capita; two systems
- Green buildings per capita; two systems
- Total green buildings; two systems
- Electricity intensity per GDP; two systems

3.2.1.2. Commonality of indicator subcategories

We found seven well-defined subcategories, and nine indicators that did not fit into any subcategory and were classified as “other.”

3.2.1.3. Findings and recommendations

Energy practices impact cities in several ways, notably the emissions of conventional air pollutants, CO₂, and other GHGs from fossil fuel combustion.

A normalizing denominator is often introduced to ensure comparability among cities of different sizes and economic characteristics. In the 16 indicator systems we evaluated, the most commonly used denominator for energy and climate is a city’s population. Some systems analyzed here used the city’s GDP. However, GDP-based energy and carbon intensity indicators lack transparency because they can be heavily influenced by macro-economic changes, for example structural shifts in the economy or the value of certain goods and services within the economy. Therefore GDP indicators might not accurately measure progress toward the goal of reducing absolute carbon emissions or energy use. Energy researchers prefer population size for this purpose because energy consumption and carbon emissions can be strongly influenced by population size, and population size is less prone to the year-by-year fluctuations exhibited by GDP-denominated indicators (Zhou et al., 2012).

GHG emissions, rather than energy use, are the most commonly used numerator in the systems we analyzed. Because energy consumption is the leading driver of carbon emissions, energy use is commonly thought of as an appropriate proxy for carbon emissions in cases where carbon emissions have not been quantified. However, the frequent use of carbon-based indicators in international

systems indicates that many city-level governments are now compiling carbon inventories rather than relying on other energy metrics.

Industrial activity, building energy use, and transportation energy use dominate cities' energy and carbon emissions profiles. None of the systems we examined look closely at the industrial sector, however. This might be because total industrial sector emissions depend upon the structure of the sector and the types of industry in a city. Researchers do not recommend using industrial GDP or industrial value-added as carbon and energy indicator denominators because of the highly differentiated market values for basic commodities versus high-value manufactured goods (Zhou et al., 2012). The indicator systems examined here did not include industrial energy and GHG emissions perhaps because of the lack of a common unit for making comparisons. However, subcategorizing cities by their industrial economic structures per unit GDP (especially by looking at the proportion of heavy industry, manufacturing, and service-sector activity) or on an energy basis may be a useful means of grouping cities together for a ranked metric of city performance.

Building energy use is commonly analyzed as an intensity of energy use per unit area of the building. However, the energy intensities of commercial and residential buildings can differ significantly because the primary functions of these buildings are different. Energy use in commercial buildings differs depending on the type of commercial activity. For example, hospitals are generally much more energy intensive than office buildings, and office buildings are generally more energy intensive than school buildings. Despite the importance of building energy use to the total carbon and energy consumption profile of cities in developed countries, only one of the systems analyzed in this report (Heine et al., 2006) included an indicator for residential energy use (total household electricity use in kilowatt hours [kWh]). Two systems (EU Green Capitals, 2011; ESMAP, 2011) looked specifically at energy use in municipal buildings (a subcategory of commercial buildings) perhaps because cities exercise a greater degree of control over energy use in their own government buildings.

Potentially because data on building energy consumption are lacking, the majority of systems analyzed here used penetration of buildings certified as "green" instead of consumption data. Two systems measured the absolute number of Leadership in Energy and Environmental Design (LEED) buildings in a given city (Boston Indicators Project, 2009; Sustainable Seattle, n.d.), and two systems measured the population-normalized number of green-certified and LEED buildings (Heine et al., 2006; Karlenzig et al. 2006). One system looked at the proportion of new and renovated buildings certified as sustainable (Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment, 2007). These green building indicators are imperfect measures of building sector energy use because green building rating systems are based on many variables in addition to energy use (e.g., water use, integration with local public transportation systems, etc.). Moreover, research has found that LEED certification does not necessarily result in lower energy consumption (Newsham et al., 2009). The appropriateness of ratings based on green building certification depends on how many LEED buildings and/or other "green building" certification systems are in the jurisdiction in question. Two systems qualitatively examined green-building support policies (EIU, 2011b; Corporate Knights of Canada, 2011).

The transportation category includes a variety of indicators; all indicators that calculate transportation-related energy and carbon emissions are included in the energy and climate primary category in this analysis. Four systems included indicators for transportation-related carbon emissions or energy consumption (EU Green Capitals, 2012; ESMAP, 2011; Boston Indicators Project, 2009; Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment, 2007). Transportation energy use per passenger distance traveled (miles or kilometers [km]) was the most frequently used indicator (ESMAP, 2011; Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment, 2007). Metrics based on energy per passenger distance traveled are a best practice because they measure vehicle efficiency. Only one system (ESMAP, 2011) examined freight transport and shipping energy, also using an energy intensity unit (tonne/km).

The most common power-sector indicator, found in five systems, measured renewable energy as a proportion of total energy supplies. Only one system (EU Green Capitals, 2012) attempted to measure the carbon intensity of electricity production. Indicators of energy security and access were rarely included, possibly because city governments have little or no influence over these variables.

Energy and climate policy indicators varied, and most were indices of several policies. The most common indicators were 1) existence of GHG inventories and reduction plans, and 2) performance compared to set targets. Renewable and building energy policies were the most common sector-specific policy indicators.

In summary, energy and climate change indicators made up a substantial share of the indicator systems we analyzed, greater than the share such indicators would have if all primary categories were evenly represented among systems (17% actual versus 12.5% theoretical average). Because energy use (as a proxy for GHG emissions) is a strong determinant of environmental health, this larger-than-proportionate share appears reasonable.

The most common indicator in the energy and climate category follows best practices by measuring per-capita GHG emissions. The dominant means of assessing energy production reform is through renewable energy indicators, which commonly measure the proportion of total city energy demand that is met by renewable energy. Key questions for such indicators are whether the city has any ability to influence renewable energy production and whether the renewable energy category includes large-scale hydroelectric power. Large-scale hydroelectric projects have significant detrimental effects on the environment, including climate change effects, so their inclusion in a renewable energy indicator would not fit with the overarching goals of an eco-city indicator system. A review of the literature indicates that large-scale hydroelectric power is often included as a renewable energy (EU Green Capitals, 2012; EIU, 2012).

The lack of other energy-efficiency performance indicators is noticeable here considering the large potential benefits of energy-efficiency programs; however, the absence of general energy-efficiency indicators might result from the fact that energy-efficiency improvements are more meaningful when

evaluated in the context of specific sectors. For example, there are more indicators for the energy intensity of the transportation and building sectors. Industry energy and carbon intensity metrics are mostly omitted from the systems we evaluated, likely because of the difficulty in creating comparable and transparent units of analysis. Energy security and access indicators are also rare (although one system [ESMAP, 2011] concentrates heavily on energy distribution system quality, using indicators such as percentage of heat loss and electricity lost during distribution). This might be because cities do not have jurisdiction to control distribution network quality.

3.2.2. Water quality, availability and sanitation

3.2.2.1. Commonality of indicators

Water quality, availability, and sanitation indicators appeared a total of 73 times in the 16 indicator systems we researched. The total number of indicators in this category within a given system ranged from zero to 12. Between 0% and 27%, an average of 10%, of the systems' indicators were dedicated to water quality, access, and sanitation issues, or, if we include the two systems that did not contain water indicators – Forum for the Future (2010) and PriceWaterhouseCooper (2011) – the average is 11%.

The most common indicators were:

- Total consumption intensity (liters/capita/time unit); six systems
- Share of wastewater treated to at least primary level; four systems
- Percentage of water lost in transmission; two systems
- Percentage of households connected to wastewater treatment; two systems
- Percentage of population using improved water source; two systems

3.2.2.2. Commonality of indicator subcategories

We found 12 well-defined subcategories, and 12 indicators did not fit into any subcategory and were classified as “other.”

3.2.2.3. Findings and recommendations

Water indicators examine four broad elements: water availability and production, water consumption and utilization, water quality, and wastewater treatment.

The most common indicator for water use in the systems we studied was total water consumption per capita, which appeared in seven systems. Two other systems restricted their analysis to domestic water consumption per capita (GCI, 2007; Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment, 2007). The second-most-common water consumption indicator looked at water losses during distribution (ESMAP, 2011; EIU, 2011b; GCI, 2007).

Water quality was most commonly evaluated against benchmarks. Six systems used national, regional, and non-governmental benchmarks to evaluate drinking, surface, and ocean water resources. Five systems measured drinking water quality, and four systems measured surface and ocean water quality.

Two systems (EU Green Capitals, 2012; Sustainable Seattle, n.d.) contained both drinking and surface water quality indicators. Most systems that were applied exclusively within the European Union and United States referenced national water quality standards.

Four systems included indicators of water use as compared to water availability. Because water production from alternative resources, such as water recycling, is expensive and relatively rare, the physical limitation of water supply is an important determinant of whether current use patterns are sustainable in the long term. Three systems examined the issue of household access to water distribution networks; this indicator appeared only in systems meant to be applied in developing countries (GCI, 2007; Esty et al., 2011; Xiao et al., 2010). Only one system looked at water recycling rates (Heine et al., 2007)

The most common wastewater indicator was the share of wastewater that was treated, found in four systems (Esty et al., 2011; Xiao et al., 2010; GCI, 2007; and EIU, 2011b). Two systems evaluated the effectiveness of treatment by measuring the extent to which water discharged from treatment plants complied with water quality standards (MONET, 2009; Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment, 2007).

Only two systems qualitatively evaluated water policies (EIU, 2011b; EU Green Capitals, 2012). Both evaluated policies on the basis of their efforts to improve surface water quality and wastewater treatment rates.

In summary, water use per capita and water quality were clear priority subcategories although there is a much greater degree of consensus regarding the importance of water use per capita than is the case for any other water indicator. Some indicator systems used water resource availability indicators to track and measure water use and ensure that water resources are not depleted at a faster rate than they are restored, an important gauge of whether a city is overtaxing its water resources. Future indicator systems should prioritize indicators such as these that evaluate water carrying-capacity. However, several issues arise in using a water availability indicator, such as whether or not water imports are included in the metric and how water is apportioned between city and non-city areas when a water source serves areas that are not contained within a single political boundary.

No single water quality indicator exactly matched any other because regulatory benchmarks are commonly referenced. A direct comparison among the stringency of the various regulatory benchmarks is beyond the scope of this report. However, the frequent use of regulatory water quality standards indicates that national benchmarks might be necessary to define the difference between acceptable and unacceptable water quality. Most water quality indicators measure the proportion of total drinking or surface water resources that meets water quality benchmarks.

The most common indicator category for wastewater is the wastewater treatment rate. Primary treatment is the preferred level of treatment. End-of-pipe indicators that measure the quality of

treatment processes evaluate an important, but significantly less frequently considered, issue: are water treatment methods effective? Relatively few systems addressed this question.

3.2.3. Air Quality

3.2.3.1. Commonality of indicators

Air quality indicators appeared a total of 32 times in the 16 systems we researched. The total number of air quality indicators within a given system ranged from zero to six. Between 0% and 25% of the systems' indicators were dedicated to air quality issues, with an average of 8%. Two systems, ESMAP (2011) and MONET (2009), did not include air quality indicators.

The most common indicators we found were:

- Annual daily PM₁₀ concentrations in milligrams per m³; five systems
- Annual daily mean NO₂ concentrations milligrams per m³; five systems
- Days per year exceeding national air quality standards; four systems
- Annual daily mean sulfur dioxide (SO₂) concentrations in milligrams per m³; two systems

3.2.3.2. Commonality of indicator subcategories

We found eight well-defined subcategories, and three indicators did not fit into any subcategory and were classified as "other."

3.2.3.3. Findings and recommendations

Air quality indicators are much less diverse than any other category; there appears to be fundamental agreement among systems on the major issues of importance. The most common method of measuring air quality is to look at the concentration of certain pollutants in city air, generally measured by milligrams per m³ of air. Air pollution was most commonly evaluated in terms of the average concentration levels measured by city-based air pollution monitoring stations although the European Union Green Capitals program separates its air pollution indicators into concentrations at stations located near traffic and those at "ambient" stations (EU Green Capitals, 2012; Berrini and Bono, 2011). Only four indicator systems evaluated actual emissions of pollutants (industrial nitrogen oxides [NO_x] and SO₂ emissions in Esty et al. 2011; industrial SO₂ emissions intensity [per unit GDP] in Xiao et al. 2010; and pounds of toxic releases in Sustainable Seattle, n.d. as well as the Boston Indicators Project, 2009). Another method of measuring air quality was to evaluate the number of days on which pollutant concentrations were above regulation limits or the number of days on which air quality exceeded national standards. Regulation-based indicators were used in four systems (Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment, 2007; Sustainable Seattle, n.d.; Heine et al., 2006; Karlenzig et al., 2007).

The most commonly examined air pollutant, PM₁₀, was included in seven indicator systems and is most commonly measured by daily average concentrations. PM emissions have been regulated by the United States, European Union, and other developed countries since the 1970s. The focus on PM₁₀ pollution is substantiated by science; studies have found that the majority of the adverse impacts of air pollution on

human health and especially human mortality are associated with PM exposure (Davis et al., 2000). However, the majority of indicator systems only measured PM₁₀ concentrations even though exposure to particulate matter smaller than 2.5 microns (PM_{2.5}) has been found to be a significantly greater health hazard (Kappos et al., 2004).

NO₂ concentrations in milligrams/m³ were the next-most-frequent indicator, appearing in five systems (EU Green Capitals, 2012; Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment, 2007; Esty et al., 2011; Forum for the Future, 2010; EIU, 2011b). NO₂ is toxic to humans and has been regulated in the European Union, the United States, and other developed countries since the 1970s. The inclusion of NO₂ as an indicator is important because this pollutant originates primarily from internal combustion engines, so it is in part an indicator of the cleanliness of the transportation sector.

Two less commonly measured air pollutants were ozone (O₃) and SO₂. O₃ is not directly emitted but is the result of atmospheric chemical reactions between NO_x and volatile organic compounds when they are exposed to sunlight. The main sources of O₃ precursors are electricity plants, motor vehicles, and chemical solvents. O₃ has both environmental and health consequences. SO₂ is mainly emitted by power plants and industrial facilities and affects both health and the environment. Indicators for these pollutants are more varied than those for PM₁₀ or NO₂, with SO₂ concentration levels being the most common indicator, found in two systems (EIU, 2011b; Esty et al., 2011).

The focus on concentration levels rather than actual emissions in the majority of air pollution indicators has both pros and cons. On the one hand, concentrations drive health and environmental consequences, and air pollutant concentration data are readily available from government monitoring stations. On the other hand, actual emissions of air pollutants drive concentration levels and are important indicators of activities that emit pollutants as well as actions to control emissions from individual sources. However, measuring actual emissions requires use of average emissions rates calculated based on fuel use as well as emissions capture rates provided by emissions sources. These data are not easily collectable and are less accurate than data sourced from air quality monitoring stations. Furthermore, actual emissions are measured in mass units and depend on economic activity, so they must be normalized to allow inter-city comparisons. The mass-based emissions values included here are given in per-GDP units (Xiao et al., 2011) and, less transparently, by land area (tons emissions/square kilometer [km²] of populated land area, in Esty et al. 2011).

There are also drawbacks to concentration indicators based on air pollution monitoring station data. Most important is the issue of relevance to local decision makers. Air pollution crosses political boundaries, so even with strong governmental efforts to control air pollution from local sources, high air pollution concentrations in cities can still result because of pollution arriving from elsewhere. Furthermore, measurability and availability of data are important because the quality and comparability of data from different cities may be in question unless there are applicable national standards regulating the placement of air quality monitoring stations. Furthermore, air quality stations in cities are rarely positioned at ground level where most air-pollution-related health impacts occur. Microclimates exist

within cities depending on building densities, airflow patterns, and emissions sources; air pollution monitoring station data often do not detect concentrations of pollutants that collect in very small urban spaces as a result of microclimate effects. In addition, although most urbanites spend a great proportion of their time inside buildings and vehicles, no system evaluated in this report included indicators of indoor air quality, which might have more impact on health outcomes than measurements of outdoor emissions. Finally, air pollution analysis based on monitoring station data is limited to the types of air pollutants monitored by air quality stations.

Some regulatory structures establish a threshold for “good air” based not on a single pollutant but a collection of pollutants. “Good air” definitions are often based on algorithms that combine air pollution impacts and are used by public health bureaus to warn residents of the health consequences of outdoor activity. Because total exposure to all pollutants is an important issue, and these regulation-established benchmarks are well-publicized indicators of air quality, this report recommends their use if they are available.

In summary, air pollution concentration metrics are by far the most common air pollution indicators. They avoid the calculation issues associated with mass-based emissions indicators. However, because air pollutant concentrations are not wholly indicative of local efforts or jurisdictional power to improve air quality, this report recommends that, if appropriate data are available, a measure of some driver of air quality that is controlled by local officials be included in air quality indicators.

3.2.4. Waste

3.2.4.1. Commonality of indicators

Waste indicators were used a total of 48 times within the 16 systems we researched. The total number of waste indicators within a single system ranged from zero to six. Between 0% and 25% of the systems’ indicators were dedicated to air quality issues, with an average of 11%, or 12% if we exclude the two indices that did not include waste indicators – ACF (2011) and Boston Indicators Project (2009). The most common indicators were:

- Total waste intensity (kg/capita/year); four systems
- Municipal waste intensity (kg/capita/year); three systems
- Household waste intensity (kg/capita/year); three systems
- Percentage of municipal solid waste recycled; three systems
- Percentage of total waste recycled; three systems
- Percentage of solid waste that goes to landfill; three systems
- Waste per household; two systems
- Percentage of industrial solid waste recycled; two systems
- Percentage of household waste recycled; two systems
- Percentage of waste that is collected; two systems

3.2.4.2. Commonality of indicator subcategories

We found eight well-defined indicator subcategories, and four indicators did not fit into any subcategory and were classified as “other.”

3.2.4.3. Findings and recommendations

The drivers of waste sector sustainability are the production of wastes and the treatment regimes applied to those wastes. Both drivers are well represented by the indicator systems examined here.

Waste production is commonly measured in mass terms normalized on a per-capita basis. Some indicator systems normalize by number of households, and one system normalizes waste generation by GDP (Esty et al. 2011, pertaining to industrial waste). Per-capita normalization appeared in eight systems (Xiao et al. 2010; Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment, 2007; ESMAP, 2011; EU Green Capitals, 2012; Corporate Knights of Canada, 2011; EIU, 2011b; Forum for the Future, 2010; MONET, 2009). Total waste was the most commonly examined indicator, appearing in five systems (EIU, 2011b, Corporate Knights of Canada, 2011; ESMAP, 2011; MONET, 2009; Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment, 2007). Five indicator systems evaluated only household waste generation (Xiao et al., 2010; Sustainable Seattle, n.d.; Heine et al, 2006; EU Green Capitals, 2012⁸; Forum for the Future, 2010). Two systems looked only at municipal waste (EU Green Capitals, 2012; Esty et al., 2011). Two systems measured other waste types; Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment (2007) measured construction and demolition waste mass per capita, and Esty et al. (2011) measured industrial solid waste per industrial value added.

In the second major category of waste indicators, waste treatment, 12 systems contained an indicator related to recycling. The most common means of measuring recycling was as a proportion of total solid wastes. We found this indicator in three systems (ESMAP, 2011; Corporate Knights of Canada, 2011; GCI, 2007). Municipal waste recycling was measured in two systems (PriceWaterhouseCooper, 2011; EU Green Capitals, 2011). Two systems examined recycling of industrial wastes (Esty et al. 2011; Xiao et al. 2010). Three systems looked at diversion of wastes from landfills (a category that includes more than just recyclable materials) (Karlenzig et al., 2007; MONET, 2007; Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment, 2007). The proportion of waste that goes to sanitary landfills was measured by three systems (GCI, 2007; Corporate Knights of Canada, 2011; ESMAP, 2011).

Although no single type of waste indicator emerges in this study as best practice, per-capita metrics are much more common than per-household or per-GDP normalization. However the type of waste included in the per-capita category is not clear. Most indicator systems measure total waste, which appears to include industrial as well as household waste. Including industrial waste is important if the end goal of the indicator is to show total resource use and the degree of strain on the waste treatment

⁸ EU Green Capitals includes indicators for both household waste and total municipal waste.

system. However, industrial solid waste contains different materials than municipal or household waste and results from production of goods for export as much from goods for in-city consumption. A landfill capacity rate indicator would better serve the purpose of measuring landfill availability or use intensity. In addition, household waste does not include waste generated by commercial establishments; as cities' economies and therefore their service sectors grow, measuring only household waste will overlook the important waste stream from commercial food and beverage establishments and entertainment venues. Therefore, we recommend total municipal solid waste as the most appropriate waste generation indicator.

Indicators of waste treatment are more varied than indicators of waste collection. Although recycling indicators were the focus in a large number of systems, these indicators measured different types of waste. Some systems included organic waste in recycling indicators; for example, Forum for the Future (2010) defines its waste treatment indicator as "the percentage of collected household waste reused, recycled, or composted." Organic composting is an optimal waste treatment strategy that limits GHG emissions from landfills and returns valuable nutrients and minerals to the soil. However, it is not included in most indicator systems, perhaps because organic waste collection is a relatively rare city service. Recycling of materials such as aluminum, glass, and paper is also a smart waste treatment strategy because it avoids the considerable energy, resource, and monetary costs of producing these materials new. Other waste treatment options include incineration and sanitary landfill treatment. There is a clear preference for sanitary landfill treatment among the indicator systems reviewed here. A drawback to many of these indicators is that they consolidate several important but distinct definitions of waste treatment, which makes them less transparent and less readily comparable from one city to another. Furthermore, a singular waste collection system and set of waste collection rate data are needed for any of these categories, which might not be available in developing countries where informal waste disposal is more common, and trash picking can be the dominant means of recycling.

In summary, waste indicators were relatively well represented compared to other primary categories (12% actual versus 12.5% theoretical, if the eight primary categories were evenly split between the indicator systems reviewed). Municipal solid waste is the best-practice waste indicator because household wastes may be too narrow a category, and total wastes, which can include industrial waste, may be too broad. For the subcategories of waste generation and waste treatment, municipal solid waste generation per capita is clearly a best-practice indicator for generation, and municipal waste recycling is the leading treatment indicator if data are available. If recycling data are not available, a second-best treatment indicator may be the proportion of municipal wastes diverted to sanitary landfills. A future indicator of interest is separate organic waste collection, but information on this is likely not available in most places today because organic wastes are not collected in the majority of cities.

3.2.5. Transportation

3.2.5.1. Commonality of indicators

Transportation indicators appeared a total of 62 times in the 16 indicator systems we studied. The total number of transportation indicators within each individual system ranged from zero to 10.

Transportation indicators accounted for between 0% and 34% of each system's indicators, with an average of 11%, or 13% if we exclude the two indices that did not contain transportation indicators (PriceWaterhouseCooper, 2011; Esty et al. 2011). The most common specific indicators are:

- Personal automobiles per capita; three systems
- Time in traffic (hours per person per year); three systems
- Km of high-capacity rail per capita; two systems
- Average commute time; two systems
- Proportion of commuters taking non-car mode to work; two systems
- Proportion of commuters taking transit to work; two systems
- Proportion of commuters walking or biking to work; two systems
- Modal split of passenger transport (percentage of total passenger miles traveled); two systems
- Proportion of the population living near (within 300 meters) of frequent public transit; two systems

3.2.5.2. Commonality of indicator subcategories

We found 10 well-defined subcategories, and 13 indicators did not fit into any subcategory and were classified as "other."

3.2.5.3. Findings and recommendations

Transportation indicators are diverse, possibly because of the diversity of available transportation data and possibly because of the varied national origins of the systems we examined. Another potential reason for diversity is that transportation decisions have a wide range of impacts on the environment and society, both negative impacts such as air pollutant emissions from fuel combustion and time losses due to congestion and positive impacts such as reduced emissions per passenger when using public transportation and the personal health benefits of active transport (biking and walking).

The literature review in Part I of this report indicates that transportation goals, in particular reduction of personal automobile use, are key for sustainable and eco-city theorists. However, few governments have imposed direct limitations on personal automobile ownership and use. Rather, cities are increasingly evaluated based on the quality and accessibility of non-personal-automobile transportation options and the rate at which residents use those options.

The most common transportation indicator was the quality of non-personal-automobile transportation options although the scope of this indicator and its denominator varies greatly among systems. Two systems – EIU (2011b) and Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment (2007) – measured the penetration of non-private transport networks throughout the city, denominated in km of public transport routes over total city area. Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment (2007) gave two penetration indicators: one for km of cycle paths per city area (km²) and another for km of pedestrian, car-free, and calming streets per city area.

Mode-based evaluations commonly sum non-automobile transportation as a share of total trips. An interesting pattern in this category is a focus on non-automobile use during commutes, which we found in five systems (Karlenzig et al., 2007; Corporate Knights of Canada, 2011; Heine et al., 2006; Sustainable Seattle, n.d.; Boston Indicators Project, 2009). Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment (2007), by contrast, looked at the share of total number of trips by transport mode and the share of total km travelled. ESMAP (2011) used two mode share indicators: the share of total trips taken by non-motorized transport, and the share of total trips taken by public transport. However, public transit use intensity metrics varied in both scope and denominator among the systems studied.

Four systems measured accessibility of public transit, and two systems measured accessibility by the proportion of residents living within 300 meters of public transit (EU Green Capitals, 2012; Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment, 2007). MONET's (2009) accessibility indicator simply measured average straight-line distance from place of residence to the nearest transit stop, and Boston Indicators Project (2009) measured housing units within a 10-minute walk from rail transit, as well as housing and services within a quarter-mile from rail.

Two indicator systems (Heine et al, 2007; Sustainable Seattle, n.d.) measured community perceptions of transportation options although not in a standardized manner. Three indicator systems focused on personal automobile ownership (GCI, 2007; ACF, 2011; Boston Indicators Project, 2009). Time-based evaluations were sometimes used although their scope varied. The most common time-based evaluation method is average time stuck in traffic per year per capita. Boston Indicators Project (2009), the SustainLane system (Karlenzig et al., 2007), and Sustainable Seattle (n.d.) use this metric although Sustainable Seattle focused on solely on commutes.

In summary, our research reveals few clues regarding how transportation in a sustainable or eco-city should be measured although a few patterns are clear. Indicators disfavor auto use. Public transportation is the most frequently measured motorized transport option. Biking indicators are much less common but more common than indicators related to walking. The environmental and health impacts of transportation received greater focus than the congestion and inconvenience issues related to automobile crowding. A few systems (Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment, 2007, Sustainable Seattle, n.d.) attempted to directly measure the distance that city residents traveled each day on the basis that any reduction in motorized transport would undoubtedly reduce the environmental impacts of transportation.

There is a correlation between certain indicators and the geographic origin of the indicator system. Systems that are meant to be applied in North America (Karlenzig et al. 2007; Boston Indicators Project, 2009; Sustainable Seattle, n.d., and Corporate Knights of Canada, 2011) focus more on mode-shifting commute transportation choices. Systems applied in Europe (MONET, 2009; EU Green Capitals Program, 2011; Forum for the Future, 2010; Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment, 2007) focus on non-motorized transportation and more often included measures of a city's bike-ability and walkability in terms of both infrastructure and

accessibility to public transit and services. These patterns make sense in relation to the types of city layouts that are typical in each place. North American cities are characterized by low density and long distances between residential communities and workplaces, necessitating motorized transport. Australia has similar low-density urban spaces. Therefore shifting motorized modes in North America and Australia (Heine et al., 2007; ACF, 2011) is a more realistic policy option than developing walkable and bike-able communities. By contrast, European cities are typically more densely populated and zoned for mixed use, so it is reasonable for Europe-oriented indicator systems to focus on improving active transportation options. Although reducing private automobile use is a priority for all sustainable and eco-cities, the transportation indicators that best measure progress toward this goal will depend on the current configuration of a city.

3.2.6. Economic health

3.2.6.1. Commonality of indicators

We found economic indicators 62 times within the 16 systems we researched. The total number of economic indicators ranged from zero to 15. Between 0% and 39% of the systems' indicators were dedicated to economic issues, with an average of 12%, or 15% if we exclude the four systems that did not include economic indicators (EIU, 2011b; PriceWaterhouseCooper, 2011; ESMAP, 2011; Esty et al., 2011). The most common specific economic indicators are:

- Unemployment rate, working age population; three systems
- Employment rate, working age population; three systems
- Average housing costs as proportion of average income; two systems
- Loan-to-debt ratio of households; two systems

3.2.6.2. Commonality of indicator subcategories

We found 18 well-defined subcategories, and 34 indicators did not fit into any subcategory and were classified as "other. "

3.2.6.3. Findings and recommendations

Statistical analysis reveals that economic health was the least commonly included category in the sustainable and eco-city indicator systems reviewed here. Only 12 of the 16 systems included measures of economic health.⁹ Furthermore, there is relatively little agreement on which indicators are most appropriate to measure economic health for eco-cities, and many economic indicators appear to have only tangential relation to environmental quality or social health.

As indicated above, economic health was most often measured with regard to the employment rate. Eight systems included indicators directly related to employment (GCI, 2007; Forum for the Future, 2010;

⁹ PriceWaterhouseCooper is somewhat of an anomaly here. Although the majority of the indicators in their Cities of Opportunity system are economic health indicators, our study examines only the 4 "sustainability" indicators in their system. That system contains many multi-sector indicators, but the format of indicator systems requires them to be placed in a single primary category, so there are likely several indicators in the Cities of Opportunity system that resemble those discussed here but were placed in categories other than "sustainability."

ACF, 2011; Corporate Knights of Canada, 2010; EU Green Capitals, 2012; MONET, 2009; Sustainable Seattle, n.d.; Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment, 2007). However, the quality of employment and the relationship between employment and broader sustainability issues were only discussed in three systems (MONET, 2009; EU Green Capitals, 2012; Xiao et al., 2010), which examined the types of jobs that were created. MONET (2009) looked at jobs in innovative sectors, EU Green Capitals (2012) measured jobs in “green sectors,” and Xiao et al. (2010) examined the number of environmental professionals employed in the city. Although the EU Green Capitals and Xiao et al. indicators bear a relationship to environmental quality, the source material for those indicators is not well defined, so a direct comparison between them is not possible.

Equity is another important issue, especially for systems applied to North America. The most common equity category has to do with housing. Six indicator systems looked at the affordability or cost of housing (Karlenzig et al., 2007; Corporate Knights of Canada, 2011; MONET, 2009; Heine et al., 2006; Sustainable Seattle, n.d.; Boston Indicators Project, 2009). Although these systems use many ways to measure housing costs, cost as a proportion of income was the most common. Income distribution indicators were found in four systems and were also most common in North American systems, especially the two individual-city systems (Sustainable Seattle, n.d.; Boston Indicators Project, 2009; Corporate Knights of Canada, 2011; MONET, 2009). Two indicator systems used the Gini index (Boston Indicators Project, 2009; MONET, 2009) whereas Corporate Knights of Canada (2011) and Sustainable Seattle (n.d.) looked specifically at the proportion of low-income residents.

The most commonly used indicators of green economic activity measured the number of farmers markets (Karlenzig et al., 2007; ACF, 2011; Corporate Knights of Canada, 2011). Innovation-oriented economic activity was also occasionally measured (MONET, 2009; Forum for the Future, 2010) as were the number of firms with certified environmental management systems (MONET, 2009; EU Green Capitals, 2012). Two indicator systems conducted qualitative policy evaluations of the degree to which the city government supported “green business” (Karlenzig et al., 2007; Corporate Knights of Canada, 2011).

Interestingly, only one system (GCI, 2007) included a metric of city-level GDP per capita, and only one other (MONET, 2009), looked at average before-tax income per capita. GDP metrics can be of potential value to an eco-city indicator system. For example, the EIU uses average GDP per capita as a normalizing metric for inter-city comparisons in its index (EIU, 2009; EIU, 2010; EIU, 2011a; EIU, 2011b).

In summary, we found some weak patterns in the economics category. Equity and employment indicators are clearly the most frequently represented, and there is much greater agreement and standardization among employment indicators than among housing indicators. The focus on employment in these indicators is interesting because it appears to be only loosely related to theorists’ sustainable and eco-city ideals as described in Part I of this report. Although housing affordability directly affects the class diversity of cities, the connection of class diversity to environmental indicators is unclear. Economic indicators that appear to have direct relationships to environmental health were

rare and highly variable, with some topics (such as farmers markets) pertaining to relatively small proportions of total city economic activity. However, economic indicators that are more relevant to environmental health may be hard to come by. Environmental activity has not traditionally been a prominent part of any economy, and metrics to measure “green” economic activity often become indices that consolidate activity across several different sectors (as seen in the SustainLane system [Karlenzig et al., 2007]). We recommend an ongoing search for economic indicators that have stronger relationships to environmental health. We also recommend constructing locally relevant indices where possible. To lower the potential cost of constructing a full set of economic indicators, it might be reasonable to include employment and equity-related statistics because these are both commonly available and often considered to be foundations of equitable societies.

3.2.7. Land use and urban form

3.2.7.1. Commonality of indicators

Land use indicators appeared a total of 79 times within the 16 systems we researched. The total number of land use indicators within individual systems ranged from zero to 20. Between 0% and 27% of the systems’ indicators were dedicated to land use issues, with an average of 14%, or 16% if we exclude the two systems did not have land use indicators (PriceWaterhouseCooper, 2011; ESMAP, 2011). The most common specific indicators are:

- Population density (persons/area); six systems
- Green space (area/person); four systems
- Housing/jobs density ratio; two systems
- Proportion of city land area protected by regulation; two systems
- Number of endangered species; two systems
- Proportion of city area that is green space; two systems
- Ecological footprint (hectares per capita); two systems
- Smart growth ranking; two systems

3.2.7.2. Commonality of indicator subcategories

We found 13 well-defined subcategories, and 28 indicators did not fit into any subcategory and were classified as “other.”

3.2.7.3. Findings and recommendations

Land use planning determines many factors that are critical to sustainable and eco-cities. Land use decisions have direct consequences for energy use and consequent carbon emissions; for example, building space per occupant largely determines building energy use, and the distance between essential services, work places, and homes can also have a significant impact on transportation energy use (ALMEC, 2011). The existence of land areas that are not built up can also affect environmental health in several ways. Protected areas and well-designed green spaces can allow biodiversity to flourish, integrate a degree of environmental awareness into residents’ everyday lives, and allow rainwater to refill critical aquifers. Density can have especially important impacts on both economic and social health. Denser communities are correlated with higher social mobility and lower costs for low- and middle-income households, as well as more opportunities to include marginalized portions of the population

such as the elderly and low-income households (OECD, 2012). Greater urban density also reduces government infrastructure costs and cost effectiveness of urban services (Transportation Research Board and National Research Council, 2002; Carruthers and Ulfarsson, 2003; OECD, 2012). Some empirical studies show that densification can also positively affect job creation, employment and skills matching, labor productivity, and innovation (OECD, 2012).

Population density is a common metric of city land use, and nine systems incorporated some measure of density, with six systems measuring population density per unit land area (EIU, 2011b; ACF, 2011; Corporate Knights of Canada, 2011; EU Green Capitals, 2012; Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment, 2007; Xiao et al., 2010). The scope of land area differed slightly in three cases: EU Green Capitals (2012) measured the population density of built-up areas (excluding green areas), and Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment (2007) and Xiao et al. (2010) focused on the density of urban areas. A less common indicator was the ratio of jobs to housing, found in GCI (2007) and Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment (2007). Unlike for other primary categories such as transportation, the geographic location to which the indicator system was intended to be applied did not correlate with whether density metrics were included.

Green spaces are commonly thought of as primarily human-constructed representations of nature within cities, with city parks being the most obvious example. Ten systems used green space indicators, and per-capita denominators appeared in six (EIU, 2011b; GCI, 2007; Forum for the Future, 2010; Corporate Knights of Canada, 2011; EU Green Capitals, 2012; Heine et al., 2006; Sustainable Seattle, n.d.; Boston Indicators Project, 2009; Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment, 2007; Xiao et al., 2010). Two systems measured green space as a proportion of total city land (EU Green Capitals, 2012; Corporate Knights of Canada, 2011). Three systems used resident access to green space (i.e., a measure of the proportion of the population living within a certain distance of green spaces) (Heine et al., 2006; EU Green Capitals, 2012; Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment, 2007). The type of indicator used did not appear to correspond to the country of origin of the systems or the area to which they were meant to be applied.

Protected lands are unpopulated spaces that are generally larger in size and less interfered with than green spaces. Protected lands can be vital environmental assets, providing habitat for native plant and animal species. Four systems included indicators of protected lands, and three of these systems protected lands as a proportion of total land area (Sustainable Seattle, n.d.; MONET, 2009; Boston Indicators Project, 2009; Esty et al., 2011). Less commonality was found in forestry and agriculture indicators, which were mentioned only in two systems (Sustainable Seattle, n.d.; Esty et al., 2007).

Biodiversity was mentioned in seven systems (ACF, 2011; Corporate Knights of Canada, 2011; EU Green Capitals, 2012; MONET, 2009; Heine et al., 2007; Sustainable Seattle, n.d.; Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment, 2007). Two

systems measured biodiversity by the presence of endangered species (Sustainable Seattle, n.d.; Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment, 2007), and the remainder of the biodiversity indicators were varied and showed few similarities.

Land use indices included Wackernagel and Rees's ecological footprint (1996), and the U.S. EPA's Smart Growth Index (2003), each of which was used in two systems (Forum for the Future, 2010; ACF, 2011; and Karlenzig et al., 2007; Boston Indicators Project, 2009).

Land use decisions are very important determinants of a city's character, as reflected by the systems examined here. Land use decisions entail high transaction costs and can drive or obstruct sustainability far into the future. Density is key issue. Decreasing density trends have been identified in many of the world's cities in recent decades. This is true in both developing and developed countries although density is reducing at a quicker pace in developed countries (Angel et al., 2005). OECD calculates that, between 2000 and 2006, population grew faster in suburbs than in urban areas across all types of cities in OECD countries, with fringe suburbanization increasing most distinctly in large metropolitan areas with populations of 1.5 million or more (OECD, 2012).

Unfortunately, it is difficult for land use metrics to account for the quality of land uses; quality is not addressed in the systems reviewed here. Merely measuring the areas of density in a city does not reveal whether those areas are well planned or are high-density unplanned urban slums where human health, environmental quality, social integration, and economic connectivity may be compromised. Other risks of urban density include higher land and housing prices, heat-island-related increases in urban air temperature; greater air pollution; decreased ability to manage and treat wastes; loss of recreational space; loss of privacy; loss of social interaction; and increased congestion (OECD, 2012). These are not necessarily fixed outcomes of density but are the outcomes of design choices.

Although green space was the most common type of land use indicator found in the systems we reviewed, the quality of green space is not commonly discussed. Only Forum for the Future (2010) used a national green space certification scheme (the U.K. Green Flag and Green Pennant awards systems) and Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment (2007) excludes green spaces under a certain minimum size. The benefits of green spaces – habitat protection, environmental consciousness raising, and aquifer replenishment – can all be lost or negatively impacted if such spaces are not planned and managed well. Although protected areas are supported by legally enforceable regulations, this does not fully address the question of quality because the strictness of regulations can vary, and enforcement of environmental protection regulations is often not prioritized.

The great variation in biodiversity indicators reflects the challenge of creating land use indicators. In many developed countries, poor environmental quality in cities has been driven by a century or more of unsustainable land use planning. Environmental remediation entails dramatically reforming these decisions, but there is a relative lack of long-term, large-scale urban environment remediation efforts on

which the appropriate factors to measure progress can be based. In short, it appears that we do not yet know exactly how to optimize the relationship between land use planning and city environmental health, particularly when new land use plans are enacted within existing cities.

In summary, population density and green space per capita are the two most common land use indicators in the systems we reviewed. Density can have especially wide-ranging positive impacts on environmental, economic, and social health, but more research is needed to determine how to integrate quality-based evaluations into density metrics and other land use indicators.

3.2.8. Social health indicators

3.2.8.1. Commonality of indicators

Social health indicators were used a total of 122 times within the 16 systems we reviewed. The total number of social health indicators within each individual system ranged from 0 to 24. Between 0% and 44% of the systems' indicators were dedicated to social health indicators, with an average of 16%, or 20% if we exclude the three systems did not contain social health indicators (PriceWaterhouseCooper, 2012; ESMAP, 2011; and Heine et al., 2006). The most common specific indicators are:

- Voting rate; four systems
- Proportion of the adult population with high school graduation or equivalent; three systems
- Proportion of the population exposed to noise levels above 55 A-weighted decibels [dB(A)] during the day and above 45 dB(A) at night; two systems
- Population growth rate; two systems
- Percentage of eligible students graduating from high school; two systems
- Student-teacher ratio; two systems
- Mortality rate of children under 5; two systems
- Doctors per capita; two systems
- Homeless rate; two systems
- Percent of adults who are active in one or more community organizations; two systems
- Percentage of adults who are regularly physically active; two systems
- Percentage of adults with type II diabetes; two systems
- Number of traffic deaths per capita; two systems

3.2.8.2. Commonality of social health indicator subcategories

We found 24 well-defined subcategories, and eight indicators did not fit into any subcategory and were classified as "other."

3.2.8.3. Findings and recommendations

Of the eight primary categories, the social health category is the most varied and thus defies simple analysis. Three social health issues are most often mentioned in the systems we reviewed: public participation rates, education availability and attainment, and health outcomes.

Public participation in the process of determining community goals for sustainability and eco-city development is almost universally prioritized by the theorists described in Part I of this report (see for

example, Maclaren, 1996; Innes, 1990), and public participation metrics play a key role in the indicator systems evaluated here. There are several means of integrating public participation into the process of planning eco-cities or more generally into environmental, economic, and social improvement efforts; however, only three systems included indicators of environmental or community planning (Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment, 2007; Sustainable Seattle, n.d.; EIU, 2011b). A more common metric, used in four systems, measured general voter participation rates (GCI, 2007; Corporate Knights of Canada, 2011; MONET, 2009; Sustainable Seattle, n.d.), with near-exact matches in the definition of the voter participation indicators in three of the four systems that included this type of indicator.

The majority of indicators used percentage of total eligible adult population as the denominator, with two systems analyzing efforts by the government to include the public in decision making (Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment, 2007; EIU, 2011b). Although public participation indicators receive approximately equal attention in European, North American, and Australian indicator systems, Asian systems do not generally use such indicators. EIU (2011b) included only a single public participation indicator (voting rate) and Xiao et al. (2010) and Esty et al. (2011) did not include public participation indicators.

Education availability and attainment indicators were included in eight systems (GCI, 2007; Forum for the Future, 2010; ACF, 2011; Corporate Knights of Canada, 2011; MONET, 2009; Sustainable Seattle, n.d.; Boston Indicators Project, 2009; Xiao et al., 2010). These indicators most commonly measured achievement, with three systems measuring the proportion of high school graduates in the adult population (Forum for the Future, 2010; ACF, 2011; and Sustainable Seattle, n.d.). Two systems measured the annual graduation rate of high school seniors out of total eligible students (GCI, 2007; Sustainable Seattle, n.d.). Two systems analyzed education attainment rates (MONET, 2009; Corporate Knights of Canada, 2011). The other most common metric was student-teacher ratio, used in two systems (GCI, 2007; Xiao et al., 2010).

Health is the third major area of focus among social health indicators. Health analysis was commonly limited to the adult population, with a focus on obesity, smoking, and physical activity. Each of these types of indicators was found in two systems. Another two systems analyzed doctors per population unit (GCI, 2007; Xiao et al., 2010). North American systems included health indicators to a much greater degree than European systems, with European systems including only one measure of health (average life years lost per person, in MONET [2009]). Two European systems included traffic accident metrics (MONET, 2009; Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment, 2007). Noise, criminal activity, equitable gender representation in local government, and homeless population were also mentioned in two systems each.

Public participation in planning has been a centerpiece of city-level sustainability efforts in the United States and Europe. Increasingly, such planning activities take place in a charrette format. A charrette is a process of building a plan through initial presentation of planners' draft designs to a broad cross-section

of interested community members and the organization of these community members into issue-specific groups to collectively work on identified obstacles (Fannie Mae Foundation, 2003).

Educational attainment is directly related to an economy's ability to adapt to dynamic market forces and create new market goods. However, highly educated individuals often earn incomes that are much higher than those of persons with less education, and higher wages can raise land, food, and transportation prices to the point where lower-paid workers cannot afford to live in the city. Lower-paid occupations include nursing, law enforcement, administrative assistant work, food service, civil service, and custodial work. These professions are essential in urban areas. Skill diversity and specialization are hallmarks of economic development, so there must be a balance between highly educated and less-educated individuals living within a city so that jobs of all levels can be filled without the need for lower-paid workers to commute long distances from peri-urban communities. Standard educational attainment of children is, in these terms, a good indicator of social health because it avoids the potentially negative impacts of an exclusive focus on more highly educated adult workers. However, higher education levels are also associated with environmental consciousness and willingness to invest in environmental improvements, and more highly educated workers can help the growth of high-value-added, low-carbon-intensity service sectors such as law, business, banking, specialty device manufacturing, and information technology services.

In summary, the wide variety of social health indicators in the systems we reviewed makes it impossible to discern patterns or identify best practices. Health, education, and public participation are clear priorities, but public participation indicators might need to be adjusted according to the political structures of the country of where the system will be applied. In particular, public participation is highly regulated in China, and voting is only an occasional activity and in all cases restricted to the local level, so voter-turnout-based indicators may be particularly unsuitable for a Chinese indicator system.

4. Limitations of this research

A cross-comparison of the sources referenced by the 16 eco-, green, and sustainable city indicator systems examined here shows that these systems are representative of the most often-cited research on city-level indicator systems. Nonetheless, our study is not exhaustive; during our research, we discovered dozens more city- and regional-level indicator systems than are analyzed here. More than 200 cities in the United States alone have adopted sustainability plans, many of which use indicator systems to benchmark and measure performance (Birch and Lynch, 2011).

In addition, this research focused on ranking rather than certification systems. Many certification-oriented indicator systems exist, and this type of system is becoming more common. Some examples are the ESTIDAMA system used in Abu Dhabi, the LEED for Neighborhood Development system used by the U.S. Green Building Council, and Japan's CASBEE cities program. Fundamental differences between the frameworks of ranking and certification systems makes comparison between them extremely difficult. For example, certification systems often allow applicants to mix and match performance in indicator categories whereas the ranking systems evaluated in this report evaluate overall performance based on scores in all indicators. In addition, most certification schemes are not punitive; if a measure is not achieved, no negative score is assessed. However, ranking systems give positive or negative scores for each indicator.

Furthermore, the authors' discretion in categorizing indicators may skew the results of the basic statistical analysis presented in this report. Many indicators address cross-cutting issues that affect performance in several categories. To simplify this analysis, we did not include any indicator in more than one category but instead attempted to place each indicator within a single, most suitable category.

Finally, the documentation of indicator development decisions is rarely exhaustive. Even the most precise and academic of the studies we reference cannot communicate every detail of the work done. Guidance documents often omit valuable information about the units of indicators, their exact definition, or their data sources. We made best efforts to remedy these problems, and some whole indices were excluded from the analysis because the documentation was of such poor quality.

Part III: Case Studies of Cities Pursuing Eco-City Goals

This section presents case studies of cities acclaimed for their pursuit of eco-, sustainable-, and green-city goals, as defined in Parts I and II of the report. The case studies focus on City¹⁰ government efforts during the past 10 years.

The first two, detailed case studies are of Stockholm, Sweden, and New York City, New York. Both have recently undertaken a broad range of efforts to improve city sustainability, including reducing GHG emissions and other actions in the categories analyzed in Part II of this paper. The cities' physical characteristics are the main focus of these activities. Stockholm's efforts focus only very minimally on social and economic issues addressed by sustainability theorists, and New York's efforts focus much more on housing availability, environmental equity (especially in regard to exposure to pollution), volunteerism, and community involvement. The two case studies describe the full range of Stockholm's and New York's sustainability efforts.

We also present three shorter case studies, of San Francisco, California; Portland, Oregon, and Vancouver, B.C., Canada. These cities have smaller populations than Stockholm and New York, so their efforts are scaled to very different needs, and they have pursued a more limited range of sustainability efforts during the past 10 years. Each has a master plan and has undertaken measures in all eight policy categories listed in Part II of this report, but the case studies of these three cities focus on sustainability efforts in particular categories: the government's embracing of green business in San Francisco, support of bicycling in Portland, and densification efforts in Vancouver. Whereas the case studies of New York and Stockholm are intended to show examples of the breadth and scope of comprehensive planning efforts, the shorter case studies are meant to demonstrate how targeted, smaller-scale efforts can achieve positive results.

The scope of these case studies is limited. Although the efforts of these cities have been lauded by several of the sources cited in Parts I and II, what has been done in these cities does not necessarily illustrate best practices for all eco-cities. Rather, these case studies are presented to analyze the development and implementation of good practices and to find common themes among these efforts.

The primary findings from these case studies are fourfold:

1. No single policy analyzed in our research has holistically and comprehensively improved environmental quality, economic growth, and social health across all primary categories. Instead, cities are simultaneously pursuing a wide variety of policies, actions, programs, and partnerships to achieve their goals. This variety is so large to that it is impossible to define best practices because there is little similarity in the policies among different cities. We know generally what the results of government and

¹⁰ In all five case studies, we use "City" to refer to municipal government and "city" to refer to the geographic area and population associated with a particular city.

civic action should be: fewer GHG emissions and reduced energy use per capita; better air and water quality; high-quality transportation with less reliance on personal automobiles; elimination of waste through conservation, resource sharing, and recycling; development of densely populated, mixed-mixed use communities close to both basic necessities and work places; economic development efforts that prioritize environmentally friendly, high-value products and services; and inclusive societies that produce and absorb high-quality intellectual capacity and provide high-quality health services. However, the means of producing these outcomes will vary based upon the historical, social, and economic circumstances of each city as well as the political contexts that define municipal leaders' scope of power.

2. Comprehensive planning is a dominant policy strategy. Comprehensive planning involves concurrently considering the widest possible scope of issues across primary categories, to identify synergies and realize co-benefits. An example is the use of waste-generated biogas for transportation and waste heat for district heating in the Stockholm case study. The Stockholm case in particular demonstrates the technical possibilities for integrating City systems. Comprehensive planning also means planning with as many different stakeholders as possible. Comprehensive planning processes are most successful when they bring together the main stakeholders in City leadership, environmental quality, energy production and distribution, land use and transportation planning, and the various utilities such as waste and potable water delivery, to talk about how to collaboratively plan for future population and economic growth, and potentially for climate change threats.

3. Planning monopolies make things much easier. Stockholm enjoys a monopoly on all utilities except electricity and owns 70% of the land in the city. This makes decision making easier than in situations where there are multiple owners and actors and speeds implementation because managerial incentives are generally aligned. New York's achievements have been more limited in the areas of energy and transportation because the City government must share planning responsibility with regional, state, and national bodies. However, it appears that planning monopolies can also create disincentives to public participation in planning processes. The planning process in Stockholm did not integrate community members as much as the planning processes in the other case studies did because community buy-in was simply less of an issue. Cities with less control over transportation, waste, electricity, gas, and water services will have to define goals more narrowly and approach stakeholders using very different, more inclusive, techniques including considerable incentives for participating.

4. Community-reliant policy and program delivery can reduce burdens on City governments. With the exception of Stockholm where community outreach and engagement is only recently increasing, every City in these case studies has traditionally relied on intensive efforts to engage community stakeholders and citizen groups to deliver both information about the City's plans and to assist with program delivery. In many cases (especially New York and Portland) community members are relied upon to implement some policies. New York's brownfields effort would likely fail without community attention, buy-in, and efforts because the issues are complex and need solutions that are tailored to fit each community's needs. Without community enthusiasm in Portland, advocates in the City government might not have been able to aggressively pursue a biking policy. These cases show that comprehensive City plans that have large infrastructure and land use reform impacts on communities can benefit from assistance from

community members. Finding ways to engage community members is a challenge for all political leaders, but the effort to do so may lower City costs and improve outcomes.

These case studies might not be applicable to all other cities for economic, geographic, historical, and political reasons. First, these four cities have rich reservoirs of capital and intellectual capacity. Their people are well fed, their economies are generally in good working order and are centers of innovation that supports ongoing economic growth, and few residents are vulnerable to extreme poverty, deprivation, or lack of social support. Higher tax revenues and more engaged communities are the result.

In terms of geography, all four are coastal. This likely makes a difference in the quality of the environment (breezes are fresher over undeveloped oceans, and precipitation is usually greater on coasts). This also likely makes a difference in land use planning decisions as well as planning of City services, especially waste capture and disposal. Oceans offer natural, built-in transportation networks for both imported products and exported wastes; there is no equivalent transportation opportunity in inland cities. Finally, all four cities have been working on sustainability issues for more than 10 years. This underscores that an eco-city cannot be built in a day; rather, gathering stakeholders together and coming to consensus about larger goals, finding the right mix of negative and positive incentives, and creating community enthusiasm all take time, diligence, and patience. The case studies presented here should be seen as evidence that the eco-city concept is being pursued and that eco-city efforts and outcomes may be determined by characteristics beyond the direct control of City managers. The results of these cities' efforts are uncertain, so this analysis must be confined to describing the ongoing efforts rather than offering a quantitative evaluation or identifying permanent successes.

These case studies illustrate that the relationship between a City and higher levels of government is important in two ways: the distribution of resources to City and local governments from higher levels of government has a significant impact on what City governments can afford to do, and planning partnerships among different levels of government can entail high transaction costs and long wait times for approvals, especially if City goals are not directly in line with state and national political currents. Stockholm's relative independence in planning its City systems and its strong ability to influence policy decisions at higher levels of government appears to have allowed for faster policy implementation than is observed in North American cities, which often have to work with regional, state, and national bodies in improving energy, transportation, air quality, and water quality management systems.

1. Case Study 1: Stockholm, Sweden: World-Renowned City Improvement Effort Centered on Eco-Districts

1.1. Introduction



Figure 3. European Green Capital Award, 2010

Stockholm, Sweden, has undertaken a long-term effort to reduce carbon emissions, protect the environment, and reduce resource consumption throughout the city, with large-scale brownfield renovation projects in special districts that incorporate with new and challenging technologies and policies. These efforts have been acclaimed in several studies: Stockholm was given the first-ever European Union Green Capitals designation in 2010 and was rated the second-greenest city in Europe by the EIU (EU Green Capitals, 2010; EIU, 2009). However, Stockholm's policies may not be easily applied in other cities because Stockholm has several unique features: the city owns more than 70% of its land, Swedish law imbues cities with a centralized "planning monopoly," and Stockholm's residents are both wealthy and highly environmentally conscious. Concentrated decision making is a significant advantage in carrying out sustainability projects, and the above factors also ensure financial and political support for the City's ambitious efforts.

1.2. Eco-districts

Stockholm has undertaken four eco-district projects, the two most important in Hammarby Sjostad and at the Stockholm Royal Seaport. Hammarby Sjostad is a long-underutilized area that was filled with small and medium-size light industries. In part for its bid for the Summer Olympics and in part because of a strong demand for more housing, the City government produced a redevelopment plan for the area. That plan targeted a reduction all environmental loads by 50% compared to city averages of the mid-1990s (Dastur, 2005; Suzuki et al., 2010). The new Hammarby Sjostad district will be completed in 2016 with more than 10,000 residential units that will house 25,000 people (Suzuki et al., 2010). The Stockholm Royal Seaport is a newer redevelopment in the city's harbor area with three environmental targets: an average of 1.5 tonnes CO₂e emissions per seaport resident by 2020 and complete elimination of fossil fuels from the district by 2030, with climate change adaptation measures (for example, sea rise mitigation measures) installed and working (Stockholm Executive Office, 2011; EIU, 2009). When complete, the seaport development will have 10,000 residential units and 30,000 office spaces.

1.3. Planning

Three elements stand out in Stockholm's environmental planning process: use of national and international policies as catalysts for change, a transition to environmental goals as dominant planning priorities, and the creation of a software tool to evaluate planning decisions.

Stockholm has been an important city in the United Nations international environmental cooperation platform, and Swedish cities have been leaders in the Local Agenda 21 effort. Stockholm has been

lauded in Europe and internationally as a leading sustainable city (Berrini and Bono, 2011). In part because of this acclaim, national policies, including grants administered through national development and climate adaptation funds, have been a catalyst for the greening of Stockholm, and in particular for the Hammarby project .

Swedish Cities take primary responsibility for municipal-level planning under the 1987 Building and Planning Act, which invests City governments with nearly exclusive planning duties and requires all municipalities to produce and regularly update comprehensive city plans.¹¹ The first plan to aggressively pursue sustainability goals was adopted by the Stockholm City Council in 1999 and focused on densification and increased mixed-use zoning efforts, promoting a policy called “building the city inwards.” The most recent comprehensive plan and its policy steering document, Vision 2030, was adopted in 2009. This plan looks to continue and strengthen the successes of the past 10 years (City of Stockholm Executive Office, 2007).

The Stockholm city plan goes through an iterative process that relies heavily on inputs from the city council, utilities, stakeholders, and academics. After the city council passes the plan, the Stockholm City Planning Administration is responsible for issuing building certificates, property and land use registrations, and housing subsidies in compliance with the plan (Stockholm City Planning Administration, 2010). For the Hammarby district planning process, a new inter-departmental team was formed, which is now called the City Streets and Real Estate Department and led by a project manager and an environmental officer. The Hammarby project also allowed the three City departments of waste, energy, and water sewage to coordinate waste streams to turn them into energy feed stocks (Figure 4).

The Environmental Load Profile (ELP) was the main planning tool used to create Stockholm’s eco-districts and has now been extended to the entire city of Stockholm. This life-cycle assessment tool was developed to forecast and track the environmental impacts of the Hammarby project. ELP models project impacts by comparing various technologies and planning choices against a business-as-usual base case. The ELP models environmental loads including emissions to air, soil, and water as well fossil fuel consumed by construction, operation, and deconstruction of buildings and infrastructure. The tool allows for scenario testing and can be scaled to predict future impacts or measure impacts after the fact, at the project, district, and city levels. The tool has been crucial in planning expansions of district heating, transportation, waste, and wastewater systems (Suzuki et al., 2010).

¹¹The national government, through the County Administrative Board, may overrule city plans if certain concerns of national importance have not been considered. See Stockholm Walkable City.

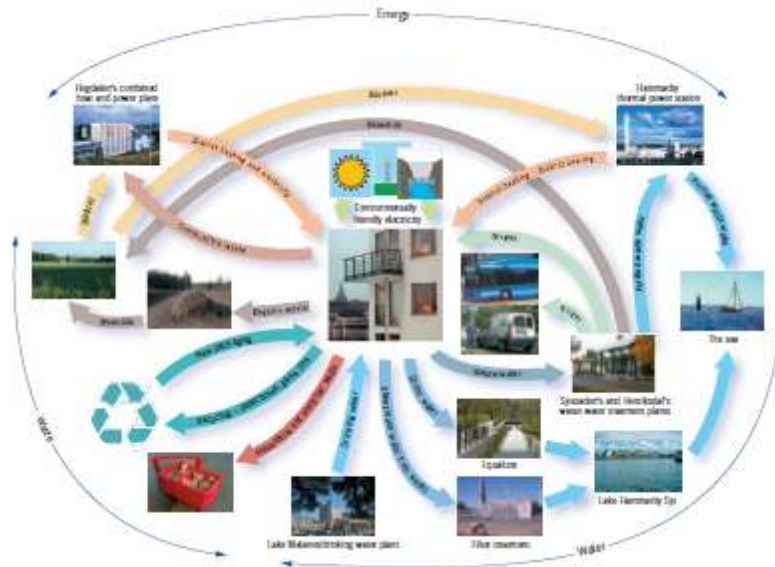


Figure 4. The Hammarby Model

Source: Suzuki et al., 2010.

1.4. Characterization by low-carbon eco-city primary categories, technologies and policies, and results

Stockholm's environmental loads have been most dramatically reduced in the areas of district heating supply and building energy efficiency, urban transportation (through mode switching), and waste and wastewater treatment. The following subsections discuss these and other primary categories.

1.4.1. Energy and climate

Stockholm has aggressively pursued policies to save energy and reduce GHG emissions in three areas: district heating, transportation, and buildings. In addition to strong energy conservation measures, all three policy areas have also involved fuel replacement. These include use of bio-wastes in district heating, biofuels in transportation, and renewable electricity in buildings.

1.4.1.1. Policy and measures

District heating and cooling: Since 1950, district heating has gradually replaced coal- and oil-based boilers and unit electric heating systems in both commercial and residential buildings (Environmental Administration, City of Stockholm 2009). The City is also experimenting with seawater-based district cooling system in 50,000 homes (Berrini and Bono, 2011).

Building Energy Efficiency: Building codes limit primary energy use in all new buildings to a maximum of 100 kWh/square meter (m^2). The City is also pursuing aggressive space-conditioning energy-efficiency retrofits, especially in existing municipal buildings and social housing.

Renewable Energy: More than 60% of the electricity consumed in the city and 20% of the city's primary energy consumption come from renewable energy resources with the average carbon content of

electricity reaching 103 grams CO₂e/kWh in recent years (EIU, 2009). Twelve percent of homes buy exclusively certified renewably generated electricity in large part because of policies requiring utilities to buy a certain proportion of delivered electricity from renewable sources, and biogas from sewage treatment is used for residential cooking (Berrini and Bono, 2011).

District Heating: Development of district heating and cooling systems has been driven by market changes and several subsidy and tax programs, as well as the municipal planning power (Environmental Administration, City of Stockholm, 2009; Ericsson, 2009). Financial drivers include national subsidies for district heating retrofits and grants for the City to expand the district heating system. Relative changes in fuel prices, a carbon tax introduced in the early 1990s, and the semi-privatization of local utilities as well as the profit benefits of combined heat and power (CHP) systems also drove the development of CHP and biomass-based district heating. In recent years, district heating benefited from economies of scale because of requirements that district heating be used in eco-districts.

Building Energy Efficiency: The energy intensity of new buildings has been largely controlled by strict building codes that apply to eco-districts. Under these codes, all new building projects must certify energy use intensity that is 50% less than Sweden's average (100 kWh/m² versus 200 kWh/m²). Municipal building energy use has been reduced by requirements for better-than-code energy performance (Berrini and Bono, 2011). Energy service companies (ESCOs) working in municipally owned buildings (including social housing) are contracted under profit-sharing schemes and are pushed to take responsibility for operation, maintenance, and follow-up for several years after the installation of measures. The City has also increased funding for capital stock investments while reducing municipal building operating budgets (Environmental Administration, City of Stockholm, 2009). Rebate and tax incentives for appliances, lighting, and district heating connections have been used to drive private building efficiency retrofits. Delivery of incentives for private building retrofits has been assisted by the Stockholm Energy Centre, a City-run advisory service that provides advice and training, especially concentrating on private housing cooperative associations (Environmental Administration, City of Stockholm, 2009).

Renewable Energy: In part because of rising oil prices and a rejection of nuclear technology in the 1970s and 1980s, Sweden has used national tax-based incentives (both positive tax incentives for renewable production and a carbon tax on fossil-fuel-based systems) to aggressively pursue centralized renewable energy (Ericsson, 2009). Rebates and feed-in tariffs are also offered for distributed renewable technologies. Furthermore, a majority of City departments have purchased all electricity from renewable sources during the past 10 years, and all City departments are doing so currently under a new collective agreement signed in 2010 (Berrini and Bono, 2011).

1.4.1.2. Results

District heating currently meets nearly 80% of Stockholm's total heating needs, and the network is being continually expanded by 200-300 gigawatt hours annually (Environmental Administration, City of Stockholm, 2009). Eighty percent of district heating energy is produced from renewable and alternative fuels, including a large amount sourced from municipal and domestic wastes. New policy targets aim for

all new construction to be carbon neutral by 2030 (Suzuki et al., 2010). The first GHG reduction goal set in 1995 was to bring the city's per-capita GHG emissions to 1990 levels (5.4 tonnes CO₂e per capita) by 2000. Emissions in 2000 were 4.5 tons CO₂ per capita, far surpassing this goal. The next goal, set for 2005, was similarly surpassed, for a total reduction of 25% of GHG emissions in 10 years (Environmental Administration, City of Stockholm, 2009). Continuing these efforts, the City plans on achieving 3.0 tons CO₂e per capita by 2015, with zero fossil fuel use in the city by 2050 (Berrini and Bono, 2011; Environmental Administration, City of Stockholm, 2009).

1.4.2. Water

Stockholm's annual per-person water consumption is 185.75 m³. Stockholm ranks poorly against other European cities in this category because of both this high water consumption and poor water efficiency policies (EIU, 2009). However, water is readily available in Stockholm, so controlling consumption is not a priority issue. The City's water sustainability efforts have concentrated on reducing pollutants in local water bodies. Many water bodies in and around Stockholm had been compromised due to poor treatment rates, industrial pollution, and uncontrolled runoff.

1.4.2.1. Policy and measures

Advanced treatment technologies have been implemented for all sewage in Stockholm. Sewage is also increasingly being used to produce biogas, which, in turn, is used to power City buses. Furthermore, special measures have been taken, mostly in eco-districts, to channel storm water to separate, less-intensive, treatment facilities. Green roofs, green area expansion, and the use of porous paving materials have also helped reduce storm water. In some high-priority water bodies, surface runoff is diverted into basins to remove oils, sedimentation, heavy metals, and organic compounds before the water reaches lakes (Berrini and Bono, 2011).

Stockholm began upgrading its water treatment practices by classifying the environmental and recreational importance of each water body and its environmental stressors. The Hammarby project allowed for the integration of sewage treatment and transportation planning through establishment of biogas treatment facilities. New district and building policies require storm water catchment basins, green roofs, and porous paving, supported by a flow-based storm water treatment charge imposed by the municipally run Stockholm Water Company (Berrini and Bono, 2011). Furthermore, the City has integrated wastewater treatment technology experimentation at many treatment sites, to drive research and development efforts (Suzuki et al., 2010). Sewage biogas systems in particular have benefited from national subsidies.

1.4.2.2. Results

One hundred percent of the city's buildings are connected to sewage facilities, and 50% of rainwater receives separate management (Berrini and Bono, 2011). Ninety-eight percent of the phosphorus and 70% of the nitrogen are removed from wastewater before it is disposed of in natural waters ((Berrini and Bono, 2011). Residents can now safely swim in all water bodies (Environmental Administration, City of Stockholm, 2009).

1.4.3. Waste

Although Stockholm's per-capita waste production was already low compared with that of other high-performing European cities, the City has during the past decade dramatically reduced landfill use rates by using the vast majority of wastes to fuel district heating plants.

1.4.3.1. Policy and measures

Waste incineration (with emissions recapture) for district heating has been a critical technology. Pneumatic tube waste disposal, in which wastes are deposited in pressurized tubes that lead to a central pick-up location, have been deployed in Hammarby, which has reduced emissions related to waste transport. National landfill taxes were introduced in 2000, which pushed the initial development of incineration technologies (Zaman and Lehmann, 2011). In 2002, the City banned landfill-disposal of combustible wastes, which further boosted incineration rates. Landfill disposal of organic waste was banned in 2005 (Zaman and Lehmann, 2011).

1.4.3.2. Results

Stockholm now generates approximately 409 kg of household waste per inhabitant, which is similar to the rate in the best-performing European cities (Berrini and Bono, 2011). Approximately one-third of wastes are recycled, and 71% of non-recyclable domestic waste is used for district heating; 2% is disposed of in landfills, mostly as incineration ash (Berrini and Bono, 2011; EIU, 2009.) Nine percent of the total amount of heat provided to the city is generated by incinerating waste. The incineration process also generates clinker for cement. The reuse of non-recyclable waste for energy improves CO₂ emissions and reduces landfill impacts; therefore, it can be considered a best practice. Most electronic wastes end up being incinerated, resulting in lost recycling potential; however, the city is planning to institute extended producer responsibility regulations (Zaman and Lehmann, 2011).

1.4.4. Air

Stockholm's air is relatively clean (poor performance in PM₁₀ concentrations but high performance in NO_x, SO₂, and O₃) compared with that of most cities in Europe, in large part because of reductions in fossil fuel use as a result of renewable power production, energy efficiency, and transportation mode changes. Stockholm's northern climate and inclement weather conditions also help alleviate the buildup of pollution levels, especially of O₃ (Berrini and Bono, 2011). Strict vehicle emissions limits have helped maintain air quality.

1.4.5. Transportation

The transportation sector is a major contributor to the city's environmental loads. Thirty-three percent of Stockholm's GHG emissions originate from transport, and inducing transportation mode change away from automobiles has been a central policy (Berrini and Bono, 2011). Slower, but equally important, successes have been realized in reducing carbon emissions from the transportation sector. The City now has a goal of 100% fossil-fuel-free public transportation (transportation fueled by carbon-neutral biofuels, renewably generated electricity, and other non-fossil fuel sources) by 2025 (Environmental Administration, City of Stockholm, 2009). Reducing transportation emissions has been among the City's

most difficult problems because it requires careful balancing of environmental, access, and mobility priorities (Stockholm City Planning Administration, 2010).

1.4.5.1. Policy and measures

Three innovations have been crucial to reducing the environmental load imposed by the transportation sector. The new eco-districts are designed to reduce the use of personal automobiles. These new districts concentrate mixed-use commercial and residential developments around centrally located transit centers, with density and population decreasing proportionate to distance from the transit center, as suggested by New Urbanism and transit-oriented development schemes. City streets have also been remodeled to include pedestrian and bike pathways, and new efficient and convenient transit services are being built, including a rail project, traffic lights that favor buses, and scheduling information systems for riders. Existing spaces are increasingly served by convenient public transportation and pedestrian networks, and residents are given incentives to use both. Transit emissions that are under the direct control of the City are being reduced. The City is also increasing the use of biofuel and ethanol-fueled buses in its fleet.

The City's 1999 Building Inward policy emphasizes multi-family housing and mixed-used buildings in new eco-districts. All new housing built since 1999 has been planned near public transit (Stockholm City Planning Administration, 2010). The City's planning monopoly makes it easy to implement new transit routes because rights of way are easily secured. Furthermore, 100% of Stockholm County's public transportation is owned and operated by the government, allowing for procurement policies to gradually change fleet fuel use. The City has joined an international consortium of cities for buying ethanol buses, to drive down the costs of new fleets. However, the most important policy was the institution of inner-city congestion taxes on private cars in 2007 after a trial period increased public support (Environmental Administration, City of Stockholm, 2009). Fuel-switching is encouraged by deployment of electric vehicle recharging stations, ethanol fuel pumps at 75% of fuel stations, incentives for taxi companies to switch fleets to alternative fuels, incentives for car-sharing and carpooling schemes, and a requirement to blend all gasoline with 5% ethanol (Environmental Administration, City of Stockholm, 2009). Transportation contributes to noise levels, and the City has banned all vehicles older than eight years as well as heavy truck traffic at night, to reduce noise (Berrini and Bono, 2011).

1.4.5.2. Results

Transportation policies have been extremely successful in shifting demand away from private transportation. Ninety-three percent of residents walk, cycle, or take public transportation to work (EIU, 2009; Environmental Administration, City of Stockholm, 2009). Stockholm now has more than four km of bike and pedestrian paths for every km² of city space and about one meter of bike path per inhabitant (Berrini and Bono, 2011). Overall public transit ridership to the city center has increased from 57% to 64% during the past 10 years, with the morning peak-hour share increasing from 72% to 78% (Berrini and Bono, 2011). Fuel-switching policies have also been very successful: 75% of the county's public transit now runs on renewably generated electricity, biofuel, or biogas, with 100% of the buses in Stockholm running on renewables (versus 30% of buses county-wide) (Environmental Administration, City of Stockholm, 2009). Nine percent of all private vehicles are ethanol, biogas, hybrid-electric, or ultra-low

emissions (Berrini and Bono, 2011). Traffic to and from the city center has declined by 20% since the imposition of congestion taxes (Environmental Administration, City of Stockholm, 2009). Transportation-related CO₂e emissions were reduced from 1.6 tonnes per capita to 1.3 tonnes per capita between 1990 and 2005, and transportation policies have contributed to a 10–15% decrease in NO_x and PM₁₀ concentrations (Environmental Administration, City of Stockholm, 2009).

1.4.6. Land use

The 1999 Building Inward policy has been critical to Stockholm's successes. Approximately 35% of Stockholm's land is used for housing and commercial purposes, and another 10% is used for roads, placing Stockholm in the middle of top-performing European green cities in terms of developed space (Berrini and Bono, 2011; EIU, 2009). Stockholm boasts approximately 4,100 inhabitants per km², compared with 3,000 inhabitants per km² in Stockholm County (Berrini and Bono, 2011). New developments are designed to house 112 persons per hectare (Berrini and Bono, 2011). Land use changes are largely incorporated in transit strategies discussed above, but eco-districts have also been important in driving land use planning and public access to green spaces.

1.4.6.1. Policy and measures

The use of mapping overlays helped City planners identify optimal brownfield development sites according to transit-oriented development guidelines (Stockholm City Planning Administration, 2010). In the recent City plan, this expanded into developing core districts that combine businesses in similar sectors (Stockholm City Planning Administration, 2010). The use of the ELP has driven outcome-based planning decisions.

The Building Inward plan coalesced City efforts to improve existing spaces through land use changes, especially promoting dense planning on brownfield sites. These policies also resulted in investments in improving parks and recreation areas and restrictions on building in designated green spaces (Stockholm City Planning Administration, 2010). The City also carried out a survey to understand how citizens use and value City parks. Survey findings resulted in better upkeep to make green spaces more accessible. (Stockholm City Planning Administration, 2010). Efforts to analyze ecological assets resulted in targeted protection and rehabilitation initiatives. Developers must remediate any ecological assets lost through development by protecting similar assets elsewhere. City managers were forced in some instances to buy land to control development, and land prices in some instances were reportedly decreased for developers who could meet strict planning guidelines. A policy is now being tried in the new city plan to direct growth specifically to a limited number of areas, facilitating land and transport planning decisions (Stockholm City Planning Administration, 2010). Another feature of the new city plan is the integration of City development efforts into regional economic and land use planning.

1.4.6.2. Results

Stockholm directs a large proportion of its new development onto brownfield lands. Of 25,000 new residential units built between 2001 and 2007, 1/3 were in brownfield areas (Berrini and Bono, 2011). Approximately 85% of Stockholm's population lives within 200 meters of parks and green spaces, and 90% lives within 300 meters (Berrini and Bono, 2011; EIU, 2009). Ninety percent of housing in the city is in

multi-family buildings (Stockholm City Planning Administration, 2010). Stockholm also boasts a large proportion of green spaces: 36% (6,870 square hectares) of urban space, or 86 m² of green area for each inhabitant (Berrini and Bono, 2011). This is an extremely large green area, even compared with the green spaces in other high-performing cities in Europe. Eight large natural and cultural reserves are protected to preserve biodiversity and citizen access (Berrini and Bono, 2011). Eight out of 10 citizens in a 2007 poll claimed that they visit a park at least once every week, and nine of 10 were satisfied with access to public green spaces (Berrini and Bono, 2011).

1.4.7. Economy and social goals

Significant economic expansion is expected for the future and has been incorporated into City plans (Stockholm City Planning Administration, 2010). The City is also expected to be a cultural center for the Scandinavian region and an economic center for Stockholm County and three surrounding counties, which together account for more than 20% of Sweden's population. The city plan therefore integrates several economic and social goals, but it is difficult to determine which of these goals are directly related to sustainability or eco-city efforts. A major economic effort is further de-industrialization of the city and financial inducements to attract green companies (Stockholm City Planning Administration, 2010). Economic planning is an important part of eco-districts in that these areas by their nature require mixed-use and local economies.

1.4.7.1. Policy and measures

Although the city is largely commercial now, de-industrialization, especially to eliminate environmentally harmful activities, continues. Efforts are being made to transform port areas into mixed-use developments so that port facilities will find new homes away from residential areas (Stockholm City Planning Administration, 2010). The City is helping oil-handling facilities relocate away from waterfront spaces (Stockholm City Planning Administration, 2010). In some eco-districts, developers are allowed to build new residential units only if they can prove that a sufficient number of jobs exist in the local area to support at least a certain proportion of the new population (Suzuki et al., 2010). The City has also recognized its role as a market participant, and management and procurement decisions are used to drive markets. For example, three housing companies and the public water utility are certified to meet International Standards Organization 14001, and the City also uses procurement to source 12% of foods prepared in public buildings as organic (Berrini and Bono, 2011). City leadership is also visible in public marketing campaigns. Hammarby has an Environmental Information Center, the Glashuset, which communicates the City's and district's goals to inhabitants and visitors (Suzuki et al., 2010). The City government has instituted a Climate Pact system, in which local companies volunteer to reduce energy use and other activities harmful to the environment within a certain period of time. The Climate Pact system provides companies with information about best practices and rewards them with publicity about their efforts. Between the pact's inception in January 2009 and May of the same year, more than 60 companies signed.

Stockholm's economy relies in large part on development of high technology, and the future of the economy and society rely in large part on efforts to continue expanding consumer knowledge and empowering consumers (Stockholm City Planning Administration, 2010). Half of Sweden's higher

education facilities are located in Stockholm County, and efforts are being made to attract new research and development efforts to these areas. In 2009 Stockholm was declared the Intelligent Community of the Year by the multi-lateral Intelligent Community Forum, in part thanks to efforts during the 1990s to create a city-wide high-speed broadband infrastructure (Intelligent Community Forum, 2009). A key feature of the city's internet infrastructure is high-speed broadband access to most schools, relying heavily on a communications infrastructure provided and operated by the City.

Social cohesion remains an outstanding issue. The eco-districts have been criticized for excluding and marginalizing social housing, and the newest City plan notes the need to progress in this area (Stockholm City Planning Administration, 2010). The City's Social Index tracks demographic characteristics and shows wide and growing disparities between affluent and poor communities (Stockholm City Planning Administration, 2010). A goal for the new plan period is increased focus on siting of schools and social assistance centers.

2. Case Study 2: New York: Dispersed City Improvement Projects in the Mega-City

2.1. Introduction

New York City,¹² America's largest municipality, expects its population (currently about 8.2 million) to increase by one million by 2030. The existing infrastructure will be inadequate to meet the needs of this increased number of residents, especially with climate-change-induced weather variability and sea level rise. To address these challenges, the City is in the fourth year of implementing a comprehensive plan, called PlaNYC 2030, which aims to decrease the city's environmental loads by reducing materials and energy use and improving natural spaces, planning for and mitigating the effects of climate change, and creating a more equitable, engaged society. Twenty-five City departments (often with state and federal agencies) are working on more than 125 initiatives, devised with the collaboration of wide range of corporate, business, and non-profit stakeholders. This group also regularly reviews the plan. New York's model relies on targeted efforts throughout the city. Execution and delivery of those efforts is assisted by community stakeholders. New York's efforts are defined in large part by the limitations that U.S. cities face: national and state level funding assists some efforts, but national and state regulations also place limits on what a City can do.

2.2. Planning

New York is developing a centralized plan that relies in large part on decentralized delivery. The PlaNYC effort began with a realization that the mayor's pro-growth agenda needed to be validated with infrastructure preparedness assessments (ICLEI USA, 2010). Predictions of large-scale needs, especially population-driven demand for energy and land, as well as a long history of sustainability measures isolated in different City departments, were the basis for City officials charged with land use planning, transportation, environmental, and energy issues to come together and create PlaNYC's interagency approach. Preparation for the City's Olympic bid helped drive the comprehensive planning (ICLEI USA, 2010). Coordinated efforts among inter-agency planning task forces, led by a single office within the mayor's office, developed the plan using data-driven decision making (starting two years before the plan was released), devising focused goals, and ensuring that stakeholders were included. Elements that support the plan's realization include citizen-oriented goals and City-organized expert stakeholder task forces, stakeholder inclusion through media outreach, plan-integrated budgets and timelines, and reliance on comprehensive data. The lead planning office was expanded and transformed into an office to facilitate the plan's implementation, designated PlaNYC project managers were placed in all concerned City agencies, and local stakeholders (sometimes at the individual building or block level) were offered incentives to take ownership of implementation. These incentives included changes in zoning codes that created opportunities for new developments, tool kits and assistance centers, and improvements in grant programs (ICLEI USA, 2010).

¹² The majority of information used in this case study for which another source is not cited is from the New York City Mayor's Office 2011 update to PlaNYC, which reviews successes since the 2007 plan and puts forward new goals for the future (City of New York, 2011).

2.3. Characterization of low-carbon eco-city categories, technologies and policies, and results

2.3.1. Energy and climate

New Yorkers pay among the highest retail energy prices in the United States, and the local electricity grid is badly congested. However, per-person GHG emissions are about 1/3 those of the average American, in large part because of dense living conditions and a high proportion of non-car travel. New York City's GHG emissions are about the same as those of the entire country of Switzerland. Figure 5 shows the breakdown of GHG emissions by source in the city.

The City has two major GHG goals: a 30% overall reduction in carbon emissions by 2030 relative to 2005 levels and a 30% reduction in government-source GHG emissions by 2017 relative to 2005 levels. Because 85% of the 2030 building stock is already built and is the source of 75% of GHG emissions (Figure 6), reducing energy use through energy-efficiency retrofits of existing buildings is the logical target of most of the City's GHG policies. Fuel switching is also important, especially reducing highly polluting heating oil used in multi-family buildings and schools and increasing gas CHP and renewables in distributed and centralized production. Climate change adaptation and resilience measures are ongoing because inner city temperatures could rise by 3–5 degrees, and sea levels could rise by more than 1 foot by 2050.

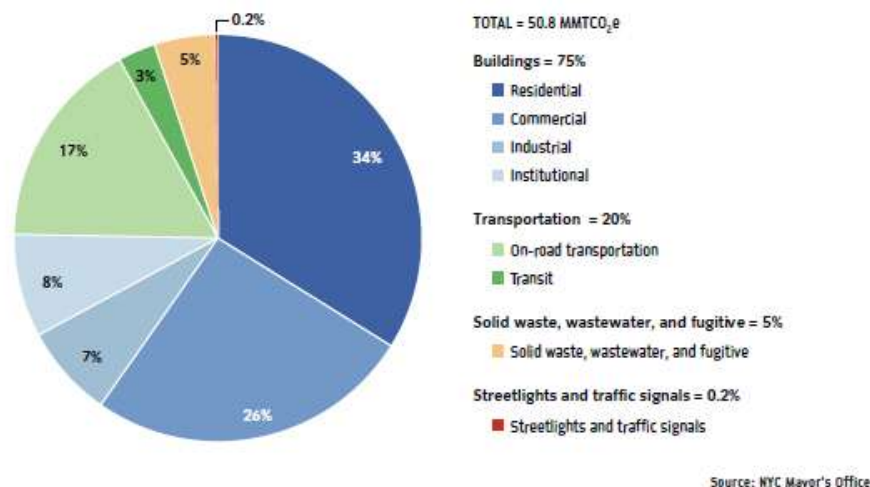
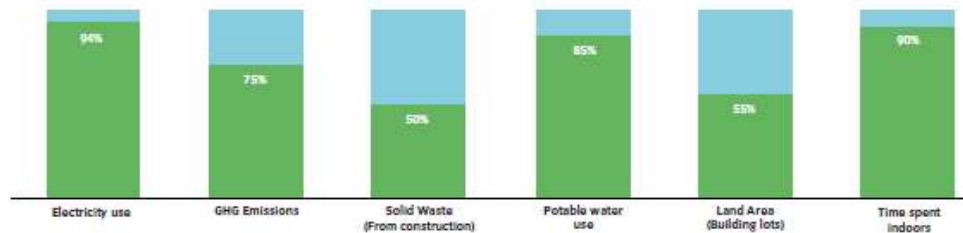


Figure 5. 2009 New York City-wide GHG Emissions by Sector

Source: City of New York, 2011.

Impact of Buildings in New York City

■ PERCENT FROM BUILDINGS
■ PERCENT FROM OTHER



Source: Mayor's Office; NYC Dept. of Environmental Protection; NYC Dept. of Sanitation; U.S. Environmental Protection Agency

Figure 6. Impact of Buildings in New York City

Source: City of New York, 2011.

2.3.1.1. Policy and measures

Building Efficiency: The City does not control or regulate local electricity, gas, or steam utilities; therefore, the City's energy-related activities are restricted to reducing energy demand in public and private buildings. This buildings effort has two major elements: the promulgation of new laws (together called the Green, Greater Buildings Plan [GGBP]) and the formation of the 200-person Green Codes Task Force (GCTF) to recommend code and other reforms to reduce a number of environmental impacts of buildings (i.e., not just energy use) (New York City, 2009; City of New York, 2011). The GGBP requires regular energy audits, retro-commissioning, and data sharing for government buildings larger than 10,000 square feet (ft²) and private buildings larger than 50,000 ft²; lighting upgrades (first in government buildings, then in private buildings); and submetering of government buildings and commercial tenant spaces. These measures will impact more than half of the space in 16,000 buildings in the city. Laws affecting building efficiency include energy codes that are stricter than state laws and equipment replacement even in renovations that affect less than 50% of a building. To ensure compliance, procedural incentives exempt from retro-commissioning and audits buildings that adopt measures early or comply with LEED for Existing Buildings, a revolving retrofit loan fund has been created with federal stimulus funds, and the City is forming a large ESCO. The GCTF's 2011 report on building codes called for 111 code, regulation, or practice changes; these are currently being implemented.

City government buildings account for 6.5% of total floor place in the city. The government is undertaking retrofits as well as including energy-efficiency measures in leases that the government signs with private building owners and creating better incentives for City building managers to save energy. The City has brought together 30 universities, colleges, unions, and professional organizations with an interest in training managers, engineers, and operators to develop workforce training programs, and the City is also developing certifications for professionals. Many universities and hospitals are trying to match the City's goals of reducing energy use by 30% by 2017.

Fuel Switching: The newly-formed New York City Energy Planning Board, consisting of City, state, and utility representatives, is planning gas distribution network expansions. The investor-owned utility, Con

Edison, has been pushed to upgrade its electrical distribution system to increase reliability, and power plant owners have also repowered two plants in the city using cleaner energy. There are national, state, and City incentives for distributed renewable energy, particularly solar photovoltaics (PV), and the utility has introduced net-metering rules. The City has developed an on-line solar map to show rooftop solar potential and two online tools (one testing using rooftop solar to stabilize the grid and other to streamline permitting processes among the grid, utility and city) are being considered. Small-scale PV and solar thermal have been installed in City-owned assets, and heating fuel-switching projects target public schools. There are informational campaigns for private buildings.

Climate Change: In 2008, the City convened a Panel on Climate Change and a Climate Change Adaption Task Force to advise the city on climate change impacts. The task force assessed climate change effects on each sector and nearly every subpart of PlaNYC, which includes a discussion of measures to reduce GHG emissions and climate change impacts (e.g., through flood-aware building codes, storm water plans, and coastline policies). Studies are planned on the water table, inland flooding, and wind and extreme heat events. A city-wide program installs cool roofs to mitigate heat island effects.

2.3.1.2. Results and future goals

Building Efficiency: The GGPB laws are expected to save more than 5% of the city's projected 2030 GHG emissions. Although most laws enacted under the GGPB have yet to take effect, energy use has been benchmarked and publicized for more than 2,700 buildings, and the City estimates compliance with private building energy data submissions to be nearly 70% (Levine et al., 2012). Energy-efficiency program funding has increased sixfold in recent years; however, funding rules are often opaque, and programs are not consolidated, so the City is working to simplify information on funding and tax incentives. Twenty-two of the GTCF's suggested changes have already been implemented. The city's one million small, medium, and historical buildings are the next policy priority. The City is also considering launching an energy-efficiency competition among neighborhoods to encourage residential savings. As for municipal building energy use, 10% of the City's budget is now committed to energy efficiency, 86 energy-efficiency projects have been carried out in City assets, and the City plans to use procurement to demand energy efficiency contracting (City of New York, 2011; ICLEI USA, 2010). Data collection and benchmarking, information campaigns, and workforce training efforts will grow to meet rising demand resulting from these efforts. The City will also pilot strategies for smarter grid management by installing energy enterprise metering systems in City buildings, allowing the use of these assets for demand response.

Fuel Switching: Changes in fuel for electricity generation have reduced the GHG intensity of electricity delivered to New York by 26% since 2005. However, the current recession and new gas extraction technology have reduced economic incentives for efficiency and especially for fuel switching. The potential decommissioning of a nuclear plant that provides New York City with up to 30% of its power will increase the need for fuel switching. The City targets developing 800 megawatts of distributed generation, including small CHP, by 2030. The City will use its own building stock to experiment with new technologies. It also plans to revise permitting requirements to make siting of distributed

renewable generation technologies easier and to work with the local utility to make interconnection agreements easier. Reducing heating oil use is a major priority; to accomplish this, the City is planning gas distribution upgrades as well as new buildings to take best advantage of efficient distribution network expansions. The City is also working to switch public schools away from oil-based heating and cooling systems. A small-scale, utility-funded, waste-gas reuse and distribution interlinkage experiment is being planned to provide gas from a wastewater treatment plant to nearby homes.

Climate Change: New York City's efforts thus far have reduced GHG emission by 13% below 2005 levels; however, much of this improvement has been outside of the City's control: power plant repowering and upgrades and better transmission of renewable generation have decreased GHG emissions by 10%, and the utility's efforts to decrease emissions of sulfur hexafluoride have reduced CO₂e emissions by 3%. Building efficiency policies are expected to contribute more than half of the GHG emission reductions targeted for 2030. City volunteer programs have led adaptation efforts, resulting in more than one million square feet of cool roofs installed by volunteers and a large number of trees planted. The hazards of climate change will be assessed in an upcoming update to the City's Natural Hazard Mitigation Plan. Ready NY, a City-run climate change information program, communicates with the public at 500 events per year regarding the effects of climate change.

2.3.2. Water

New York's drinking water is high quality, and supplies are currently secure. Because of highly successful conservation efforts, consumption levels per capita today are lower than in 1950, despite dramatic increases in the late part of last century. The major water issue in New York is the impact of wastewater on local water bodies. Domestic and industrial effluents are well treated, but storm water capture poses major challenges. Another major challenge is restoring and preserving the ecology of New York City's 520 miles of coastline. Another City goal is to improve public access to tributaries from 48% to 90% by 2030. About 7% of the city's GHG emissions result from methane vented at wastewater treatment sites.

2.3.2.1. Policy and measures

National laws regulate effluent and drinking water quality standards, and the City's efforts are largely in response to these requirements. PlaNYC addresses the securing of potable water supplies, especially from potential dangers of climate change and degrading distribution infrastructure. New ultraviolet treatment technology is being introduced to reduce the use of treatment chemicals. Automated monitoring devices are being installed for every water load in the city to allow for metered water billing. Conservation measures continue through tap replacements, stricter building codes, and City-sponsored design manuals for water conservation in buildings. To reduce GHGs, the City plans on reusing at least 60% of the gas produced in anaerobic digesters at wastewater facilities.

The City directly owns wastewater facilities, is in the process of upgrading plants to increase capacity, and in 2010 dedicated a large fund to reducing nitrogen in effluents. To reduce the risks of new technology, the City has tested many of the technologies being deployed. A Sustainable Storm Water Management Plan was developed in 2008, and pilot projects are testing implementation of control technologies such as swales, tree pits, green and "blue" roofs, and permeable pavements. In peri-urban

areas, wetlands and other green spaces are being used to filter storm water before it enters water bodies. Storm water capture and treatment are being driven by incentives (tax incentives for green roofs), and the City is studying imposing disincentives such as revising storm water charges and creating storm water capture zoning requirements. New City-funded grants support implementation of comprehensive runoff water management measures for local communities, and community-driven tree planting is helping with storm water capture. New planning codes are being designed to better address runoff from unenclosed industrial areas. The City has invested more than \$6 billion in harbor water quality improvements since 2002, and a city-wide wetlands management plan has been constructed as part of PlaNYC. Wetlands restoration work continues, with wetlands management assigned to appropriate departments and through cooperation with state and national efforts, especially in reforming developers' wetlands impact mitigation requirements to create higher-value restoration efforts.

2.3.2.2. Results and future plans

Incentives fueled a large-scale toilet, showerhead, and faucet replacement scheme during the 1990s, which led to dramatic savings of potable water. Since 2007, more than \$7 million has been dedicated to water quality improvements, and storm water capture has improved from 67% in 1994 to more than 72% today. One hundred percent of the city's sewage is now treated by 14 plants, and the City has 100% certified attainment of Clean Water Act secondary wastewater treatment standards for the first time ever. The harbor is reported to be the cleanest it has been in 100 years, with 75% of water area meeting pathogen standards for swimming. The City is exploring ways to amend its highly illogical storm water and sewage use fee. However, much work still needs to be done; treated wastewater still contains high levels of nitrogen, and storm water management still occasionally requires dumping sewage into the harbor although at a decreasing rate. Contaminated sediments remain an outstanding problem in some waterways. Long-range visions for waterfront improvement have been established in a waterfront plan (New York City Department of City Planning, 2011).

2.3.3. Waste

The city generates about 14 million tons of waste per year, with almost equal portions coming from commercial, residential, construction, and fill. Because all City landfills have been closed, the City must transfer landfill waste elsewhere at a great cost. Organic wastes make up 30% of residential waste and 18% of commercial waste, but there is no curbside collection of organic materials and little collection of yard waste. Residential recycling rates are less than half of what is technically feasible, and only about half of all wastes are recycled currently; see Figure 7 for details. Three percent of the city's GHG emissions result from solid waste. Toxic materials make up less than 1% of the residential waste stream.

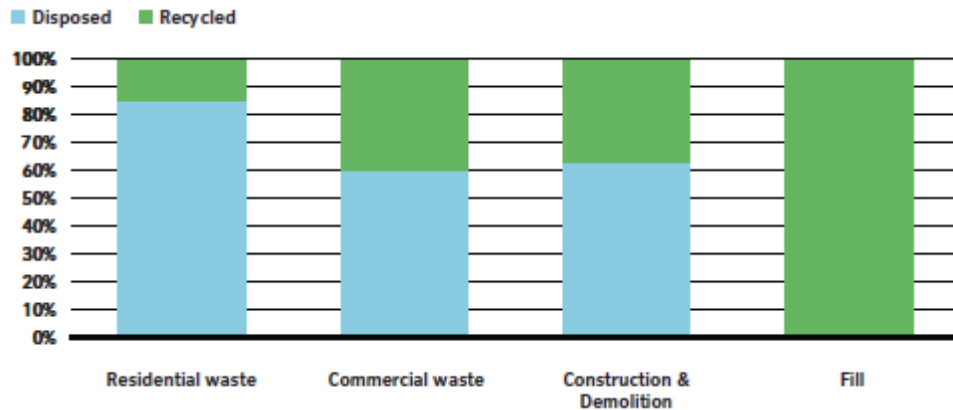


Figure 7. Diversion Rate by Waste Stream

Source: City of New York, 2011

2.3.3.1. Policy and measures

PlaNYC aims to divert 75% of all solid wastes from landfills. The majority of the plan’s goals for wastes originate in the Solid Waste Management Plan, passed in 2006. Many goals optimize the City’s control over waste collection and treatment or relate to City-controlled assets. Inequitably distributed waste transportation burdens in some neighborhoods are being reduced by new City mandates to collect and locally treat waste, and waste that cannot be treated locally is increasingly being transported by boat to reduce transportation-related air emissions. To reduce GHG emissions and other air pollutants, new treatment technologies such as anaerobic digestion and thermal processing are being used. City department managers are being given incentives to reduce waste and increase recycling, new street recycling bins have been added, and road repairs increasingly use recycled asphalt. Public schools are now required to develop sustainability plans that account for waste and recycling, and the City has created new environmental procurement rules and packaging reduction guidelines for its contracts.

Other goals address waste education campaigns and regulations to reduce private consumption and increase recycling. The City has launched four major public education campaigns on composting, disposable water bottle use, plastic bag use reduction, and paper recycling. Enabling strategies that accompany these programs include new locations for disposal of organic materials, fountains for refilling bottles, and retailer plastic bag collection and recycling laws. The City is also working with food businesses to find ways to reduce food packaging. On-line and real-time programs are being organized to facilitate trading of citizen and corporate used goods. Curbside organic materials collection, which failed in a pilot conducted 20 years ago, is being studied again, and the City is approaching community groups to increase small-scale composting. The City is also testing strategic rewards programs to increase residential recycling. City-run on-line databases now publish community-scale recycling data to enable community-based organizations to target their initiatives. The New York Housing Authority is also forming Resident Green Community Groups to expand recycling education in housing developments and imposing penalties on large buildings that do not comply with recycling rules. Efforts to reduce toxic materials include a pilot partnership with paint manufacturers and retailers to take back paint products and a new state law mandating that electronic manufacturers collect and recycle electronic waste (“e-

waste”) as well as prohibitions on landfill e-waste disposal starting in 2015. Commercial waste production and disposal are poorly understood, and efforts are under way to increase data collection and analysis on these topics. In the meantime, the City is promoting collection and refining of restaurant grease for biodiesel by streamlining operational permitting. A trial program for on-site organic waste recovery is targeting large-scale commercial organic waste producers and includes a program to reward sustainable solid waste management practices.

2.3.3.2. Results and future goals

Waste generation citywide and per capita has decreased during the past 10 years although not necessarily as a direct result of City policies. However, the City has improved many of its waste management operations as a consequence of both earlier efforts and new programs under the 2006 Solid Waste Management Plan. Thirty percent of the city’s waste leaves on rail, and barge transportation is expected to increase when two marine transfer stations are completed. A large-scale recycling facility is slated to open by 2013. Efforts to influence the private sector have been less successful. Plastic bag recycling programs for retailers have been nearly ineffective, for example. Policymakers see household plastics recycling as a key area to address. The City is making efforts to expand the types of plastics that can be recycled. In addition, waste fees are changing so that they will be based on actual disposal rates rather than flat property taxes, and the City is targeting free recycling collection as a part of these efforts. This program will be difficult to implement in some cases, especially considering the challenges of mass-based fees in multi-family housing units. The City is also working to enact mandatory recycling programs for construction and demolition materials.

2.3.4. Air

New York City’s air fails to meet federal O₃ and PM_{2.5} standards, and air pollution patterns mean that adverse health risks are often concentrated in low-income neighborhoods. Overall, air pollution causes 6% of annual deaths in the city. The City will likely fail to meet future national air quality standards for NO₂ and SO₂. Failure to meet federal air quality standards not only creates health risks but imposes legal limitations on economic development because it results in restrictions on the permitting of new emissions sources. The City’s goal is to have the cleanest air quality of any major U.S. city by 2030, which will require a 22% decrease in 2005 PM_{2.5} levels. Sources of pollution within the city include heating oil combustion, vehicle emissions, and emissions from electricity generation and other building sources; however, many pollutants originate from outside the city, which restricts the City government’s ability to meet air quality improvement goals.

2.3.4.1. Policy and measures

The city’s air is regulated at the state and national level, so the City government has few options for improving air quality other than taking indirect steps that affect building energy use and transportation policy and lobbying state and national legislatures to improve air quality law. The City lobbies state representatives to preserve regulations that decrease emissions upwind of the city and to allow the City to offer cleaner transportation incentives and set fuel economy standards. However, these efforts entail significant transaction costs, and a City fuel economy standard established in 2007 was invalidated. The City successfully lobbied state lawmakers to require a significant decrease in heating oil emissions and to

support fuel switching and continues to lobby for the elimination of tax exemptions for a highly polluting boat fuel called bunker fuel. The City has also partnered with the Port Authority and federal agencies to produce a Clean Air Strategy for the port (which is not directly controlled by the City) to reduce criteria pollutant emissions by 30% and GHGs by 50% from 2006 levels.

The Community Air Quality Survey, launched in 2008, helps the City focus its fuel reduction efforts. City laws mandating total fuel replacement by 2030 are targeting buildings using highly polluting heating oil. The City is also reducing diesel use in its fleet, shifting City fleet use (for instance by increasing transportation by water and local treatment of solid wastes), and phasing out school and other municipal building boilers that use highly polluting heating oil. The retirement age for City buses has been lowered, and indoor air filters have been installed in buses. The City's public and private ferry fleet has also been the target of fuel switching. Tree planting campaigns are concentrated in high-asthma neighborhoods. The City is also using information campaigns to reduce vehicle idling and to target owners of buildings heated by fuel oil. City procurement programs restrict the purchase of carpets that compromise indoor air quality and other goods that emit volatile organic pollutants.

2.3.4.2. Results and future plans

Actual air quality, especially PM_{2.5} concentrations, has improved in recent years. Thirteen schools have received new boilers, and 200 more will phase out heating oil by 2015, with the city prioritizing boiler replacement in high-asthma areas. The achievement of air quality goals is expected to save more than 700 lives, 500 hospitalizations, and 1,400 emergency room visits every year.

2.3.5. Transportation

About one-third of all trips in New York are made by public transit, one-third on foot, and one-third by car. Fifty-four percent of households own a car but use it relatively infrequently, with public transit the clear preference during commute hours. The City's transportation infrastructure faces large budget shortfalls, and the City's ability to add transit capacity is limited. The taxi fleet carries more passengers than most public transit systems in the country, and most customers state that taxis help them live without a car. However, taxi services are confined to the inner city, and a large taxi black market operates outside of City regulation. Almost 90% of the city's freight is transported by heavy truck. The City owns 26,000 vehicles and pieces of motorized equipment. The fuel mix for delivered electricity is favorable, in terms of GHG emissions reductions, for the use of electric vehicles, but demand may outrun supply.

2.3.5.1. Policy and measures

Fuel Switching: The Clean Fleet Transition plan aims to reduce City's fleet size by 5% and switch fuels in the remaining fleet. Sixty electric vehicle charging units have been installed at City-owned facilities and garages, and low-emission fuels like biodiesel blends and electric hybrid engines are being piloted in buses. To increase the availability of electric vehicles, the City is partnering with Boston, Philadelphia, and the local utility to collaborate on overcoming the technical barriers to at-home electric vehicle charging stations. Meanwhile, the City is using federal funds to install street and parking lot chargers. The New York State Energy Research Development Authority manages a federal fund that helps private

fleets retrofit vehicles and switch to alternative fuels. The City is also using information campaigns and stronger procedures to better enforce vehicle anti-idling laws and increase knowledge of electric vehicle benefits.

Efficiency: The state has imposed payroll “mobility” taxes and a taxi surcharge as well as other motor vehicle fees in recent years, but a City-led effort to impose a congestion tax was rejected by the state legislature. The Metropolitan Transit Authority (MTA), a regional transportation board, has launched its first bus rapid transit line. The MTA is also testing a ferry service to serve waterfront communities and continues to expand the subway system. The MTA has also piloted a real-time bus scheduling information system to reduce rider wait times at stops; this system is being gradually expanded. The City is also working to double the number of bike lanes, provide protected bike lanes, and improve bike parking at transit hubs. A bike-sharing program is being piloted throughout the city in 2012, which offers free use for trips of less than 30 minutes. Measures to increase pedestrian safety include better traffic signals, new regulations regarding parking lot entrances, and the Safe Routes program (which reduces traffic speeds and increases the number of crosswalks in high-pedestrian-density zones).

The Green Light for Midtown program has simplified traffic patterns, improved pedestrian safety, and created new public plazas. The City has also installed more parking meters to increase parking capacity, and parking charges have been increased to reduce demand. A few pilot programs are installing wireless sensors to direct drivers to open parking spaces and thereby reduce traffic. New York is already the largest car-sharing market in the nation, and the City is encouraging expansion of programs through new zoning requirements that include spaces for car-sharing programs and using car sharing for City fleet vehicles. To reduce the impact of freight traffic, the City is working with centrally located businesses to voluntarily shift deliveries to off-peak hours and is imposing time-of-use charges to induce delivery shifting. A long-term goods management plan is being constructed for the port, and the City is looking into increasing rail and water transport, especially for wastes, as mentioned above. The City is lobbying the state government to change state procurement rules to help rationalize street repair programs, especially for street work related to utilities.

2.3.5.2. Results

Since 1999, most growth in intra-city travel has been accommodated on transit, resulting in the highest subway ridership levels ever experienced in the city. Figure 8 shows the ongoing improvements in public transit ridership. Bike commutes have tripled since 2000, and the City aims to double bike commuting compared 2007 levels by 2012 and triple it by 2017. Pedestrian traffic fatalities have decreased by 35% since 2001. The City already boasts the largest clean vehicle fleet in the country – about 6,000 City-owned vehicles are hybrid or alternative fuel vehicles. The New York State Energy Research Development Authority fund has helped retrofit 280 private trucks so far, and another 400 vehicles are targeted in the program. Thirty percent of the city’s taxi fleet is now hybrid or clean diesel. However, the transit network is underfunded; recession-induced payroll decreases cut into mobility revenues, forcing cost reductions through a decrease in transit services.

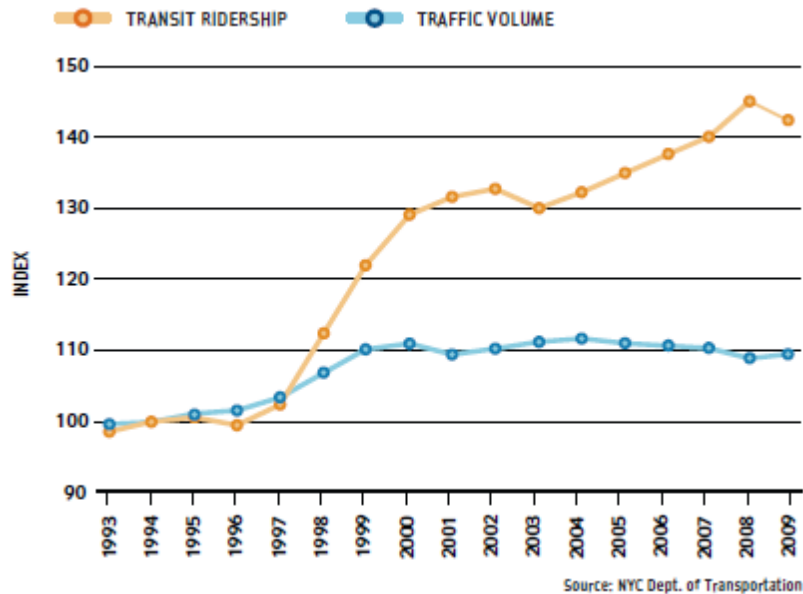


Figure 8. New York City Traffic Volumes and Transit Ridership

Source: City of New York, 2011.

2.3.6. Land use

Providing housing for the one million additional New York residents expected during the next 20 years is a top priority. The City is also expecting demographic changes, with the median age increasing and more elderly and single households rather than families. The percentage of New Yorkers living close to transit decreased during the past half-century, so improving density is a key to the City's GHG goals. In terms of green space, more than 25% of the city is parkland, with most owned by the City but some parcels owned by the state and federal government and private owners. Even so, two million New Yorkers still live more than a 10-minute walk from a park; the City plans to increase to 100% by 2030 the number of residents who are within a 10-minutes walk to a park.

2.3.6.1. Policy and measures

During the past 10 years, the City has frequently used zoning regulations to create dense, transit-oriented new developments. Reforming brownfields and increasing access to green spaces are goals toward which the City is working now.

Rezoning: Comprehensive rezoning may be undertaken to preserve the historical character of a neighborhood, promote development, or both. New zoning rules usually prioritize density (especially along key corridors and at transit hubs) and mixed-use development. Community outreach efforts proactively seek out local stakeholders to generate recommendations and elicit buy-in for land use and zoning changes. These collaborations can be a rich source of information about opportunities to improve walkability, traffic safety, and connections between residents and jobs. The City is integrating a healthy foods movement into its rezoning efforts, especially in low-income communities that do not have sources of fresh food; financial and zoning incentives are promoting full-service supermarkets in

underserved communities. To entice residents to shop locally, neighborhood shopping districts are being encouraged through the City's Neighborhood Retail Strategy, and a local retail zoning "toolkit" is designed expand the use of zoning tools to address retail issues in the city's many commercial areas.

Brownfields: Redevelopment of unused land is a primary priority of PlaNYC, and efforts are being made to strategically target new construction funding in areas where co-benefits can be realized by brownfield developments. To lead the brownfields effort, the City has created an Office of Environmental Remediation, the nation's first such City-run effort. This office has been engaging community stakeholders to educate them about redevelopment while minimizing the uncertainty of investment and cleanup requirements by streamlining the permitting process and using City resources to increase liability protection for developers. The Brownfield Partnership brings 50 community-based organizations and environmental businesses to the table to educate stakeholders, support planning, and encourage grassroots community organizing. Twenty-five new Community Brownfield Planning districts are being established to create on-line information resources and community brownfield development plans. The City intends to provide grant and other incentives to projects that comply with community brownfield plans. The City is also helping administer state grant programs aimed at communities with numerous brownfields.

To assist developers, a searchable on-line brownfields database has been created with comprehensive environmental and historical data on more than 3,150 properties. The City is working with state and federal regulators to create exemptions to rules requiring cleanup before real estate transactions and is lobbying state lawmakers to create exemptions from state and federal liability laws for projects that cooperate with the City's program. The New York City Green Property Certification Program is being created to standardize quality assurance practices. Smaller developers are being assisted with an on-line information portal combining permit applications, guidebooks, real-time project tracking, and access to project archives. A pro bono expert environmental consultant panel has also been created to help small and medium developers through the process. The City is trying to use its experience with high-quality cleanups to assure potential lending partners that the efforts of participants in the City program will be similarly high quality in order to minimize interest rates. This effort includes City-owned lands. Reclamation of unused buildings, such as old hospitals and public schools, is providing additional affordable housing. The City is also looking to reduce its land footprint and find opportunities to consolidate building space.

Green Space: New York City's main community-integrated redevelopment effort is the Greener, Greater Communities program. To increase residents' proximity to green space, school yards are being used as after-hours parks, existing destination parks are being improved and new ones created, and small outdoor spaces are being established in commercial districts. Community and inter-government partnerships are essential to this program. The City is creating a scorecard to evaluate communities based on green space goals and to find opportunities to maximize investments through community partnerships. Grant programs have been created to allow community groups to operate temporary play-space-oriented street closures. A Street Design Manual, educational programs regarding park and tree maintenance paired with grants and free tools, a large-scale volunteer-driven tree planting scheme, and

research into street tree mortality are all tools to help community groups green their neighborhoods, become stewards of local parks, and ensure the long-term viability of green-space improvements. An on-line stewardship tool is being constructed to help track these efforts. The program also targets city gardens, which have long existed in New York, but volunteer numbers are growing with city encouragement. Because 40% of the City's parks are not on city land, the City government is working with state and federal agencies to align rules to increase access. City codes are integrating landscape issues, and municipal construction landscape standards are under development.

2.3.6.2. Results

Rezoning: Since 2002, the City has undertaken comprehensive rezoning efforts in 109 neighborhoods. Eighty-seven percent of new housing developments are within a half-mile of transit, compared with 70% of all households.

Brownfields: The City has paid \$800,000 to support cleanup on 16 lots, which is expected to leverage \$165 million in new development and to create 500 new jobs. The on-line brownfields database registered more than 500,000 hits during its first five months of operation, and the City is assessing the condition of 1,000 at-risk buildings and will consider transferring these assets to owners who can better manage them.

Green space: Since 2007, the City has managed to increase "10-minute walk to park" access for a quarter-million residents. A large part of this success has resulted from transforming 180 schoolyard playgrounds into parks as mentioned above. More than 430,000 new trees have been planted since 2007, and another quarter million will be planted by the end of 2013, as part of the intent to plant one million trees planted by 2030. In 2009, the Housing Authority created 37 Resident Green Committees to promote small-scale efficiency, tree planting, and other greening efforts.

2.3.7. Economic and social goals

New York is home to residents from all parts of the income spectrum. The election of Mayor Bloomberg in 2001 heralded a pro-growth reform effort, concentrating in large part on rezoning and redevelopment plans (ICLEI USA, 2010). These have been largely integrated into PlaNYC, especially the brownfields effort. However, the plan focuses mainly on the city's physical infrastructure rather than a more expansive definition of sustainability that includes social and economic factors (ICLEI USA, 2010). We discuss a few key measures here: affordable housing, pollution equity, and food access.

2.3.7.1. Policy and technology measures

Housing: New York's population is expanding faster than the housing stock, and housing has become less affordable to a larger proportion of the city's population, with more than half of households now spending more than 30% of their gross income on housing. The mayor's office has implemented a New Housing Marketplace Plan with affordability programs targeting low- and medium-income sectors. Affordable housing creation and preservation are the main targets of the policy, and energy-efficiency efforts are being undertaken in program properties to increase affordability. Financial incentives for developers include floor space limit waivers for developments that provide a proportion of low-income

housing. The New York Housing Authority and community stakeholders have become valuable partners in identifying areas ripe for development and rezoning. To create more space for households that are expected to be smaller in the future, the City is looking into regulatory changes that would allow converting one and two-family homes into multiple apartments. All City-financed housing projects must comply with third-party-designed green affordable housing guidelines; outreach efforts in non-City-financed buildings look to educate owners about how to reduce tenants' energy bills. City financing, especially for needed infrastructure upgrades, is essential to many of these projects, and affordable housing preservation efforts are spurring the creation of financing arrangements that increase access to property tax incentives, low-interest financing, and other instruments if owners commit to long-term affordability.

Pollution Equity: The Air Quality Survey undertaken in 2008 found the effects of air pollution, especially asthma rates, to be inequitably distributed around the city. Waste transportation and treatment are often concentrated in lower-income boroughs, and the City is now mandating in the Solid Waste Management Plan that waste be treated in the same borough in which it is collected, reducing transportation exhaust and waste-related emissions. Waste collection contracts are the main means of implementing this strategy. Schools in low-income communities disproportionately use highly polluting fuel oils, so boiler replacements have targeted these schools. Tree planting efforts have concentrated on three high-asthma, low-income neighborhoods.

Food Access: Basic services are not evenly dispersed throughout the city; for instance, more than three million residents live in areas with limited opportunities to purchase affordable, nutritious foods. To understand this problem better, the City government is researching the city's food shed. Regulatory efforts promote the sale of healthy foods through the use of City food cart permitting processes and food stamp assistance programs, targeting, by means of supermarket development incentives, the creation of 300 new healthy food retail options in underserved areas. The City is also funding Initiatives to train small-scale entrepreneurs, such as restaurateurs, in low-income communities. Food garden expansion is also a target for low-income communities.

2.3.7.2. Results

Since 2004, 110 affordable housing units have been either newly constructed or preserved, and the City aims to expand this to 165,000 units by 2014. Floor space limit waivers have resulted in 1,900 additional units of permanently affordable housing since 2005. No results could be found to assess whether pollution equity and food access programs have been successful; it could take years to see the results of these programs.

3. Case Study 3: San Francisco CA: City-Directed Economic Incentives for Green Businesses

In 2011 the EIU recognized San Francisco as the greenest major city in North America; two years earlier, SustainLane ranked the city second among the United States' largest 50 cities (EIU, 2011a,b; Karlenzig et al., 2007). San Francisco has many features that create a friendly environment for sustainability and innovation, including high per-capita income (\$60,300 in 2008) and a highly educated work force: 50% of San Francisco residents have higher education degrees, and 89% of workers are in the service industry (San Francisco Planning + Urban Research Association, 2008; EIU, 2011b). The high incomes and proportion of educated professionals may be in part because of the environmental amenities the city offers. The city's mild climate, natural assets, and history of embracing new ideas have attracted leaders in environmental protection and energy technologies from all over the world. Two major universities and two U.S. Department of Energy national labs are located nearby. Silicon Valley has concentrated wealth and brain power in the region, and the California state government is very supportive of clean technology businesses.

The City has long used regulatory devices to spur the market for green buildings (through municipal building codes and prioritizing the processing of permits for highly ranked green buildings) and consumer demand for clean technologies (through city-level grant and tax incentives for distributed solar generation). Additionally, the City has the United States' longest transit system and uses its waste collection monopoly to pursue aggressive waste policies. In 2002, the City passed a climate action plan with a commitment to reduce GHGs by 20% below 1990 levels by 2012. The U.S.'s first eco-district is being planned by the City. San Francisco is especially notable for its efforts to boost the market for cleaner products through City procurement practices and various other efforts to make the city an attractive place for green and cleantech companies.

3.1. Policies and measures

Green Procurement: Cities are large consumers of products that have negative environmental effects, such as basic chemicals (paints, janitorial products, etc.) and office supplies (paper, batteries, etc.). San Francisco spends more than \$7 million buying such products each year and is dramatically increasing the amount spent on green products because of a recent law requiring that all agencies use a list of City-approved, environmentally friendly products in 10 different categories. After initial testing of green procurement for chemicals in 1998, the board of supervisors in 2003 passed a law requiring that the City to make all decisions based on the precautionary principle.¹³ To implement this law, the board of supervisors promulgated the 2005 the Precautionary Purchasing Ordinance,¹⁴ which makes the City's

¹³ The Precautionary Principle Ordinance requires that the City: take anticipatory action to prevent harm; address the community's right to know about the potential human health and environmental impacts of all products; assess the full range of alternative purchase decisions; take reasonably foreseeable life-costs into account; and employ participatory decision-making processes.

¹⁴ *San Francisco Municipal Environmental Code*, Chapter 2

Department of the Environment (SFDE) responsible for maintaining a list of approved products and ensuring that City agencies are aware of the mandate and are complying. Beginning two years ago, the SFDE created an awards program to recognize best-performing City agencies. The SFDE also provides consultation to increase City staff awareness and assist with compliance (San Francisco Commission on the Environment, 2006).

The Green Business Program and Cleantech Business Incentives: The San Francisco Green Business directory is a green business certification program administered by three City agencies (the SFDE, the Department of Public Health, and the San Francisco Public Utilities Commission). The directory's purpose is to help San Francisco businesses adopt sustainable and profitable environmental practices by following guidelines for waste reduction, energy and water conservation, and pollution prevention. Certification is performed by government auditors. Certificates are valid for three years, with self-recertification reports required after the first two years. Businesses eligible for certification are hotels, restaurants, offices, retailers, dentists, garment cleaners, janitorial services, and caterers. SFDE has established individualized standards as well as tailored toolkits for each business type. The program incorporates two incentive mechanisms: certified businesses get public recognition and are preferred for City department purchases under the procurement ordinance. Since 2005, designated clean technology businesses that meet the Green Business standards are eligible for 10-year local payroll tax exclusions.¹⁵ Other tax incentives for cleantech startups include a pre-initial-public-offering stock-compensation tax incentive and low-interest loans for businesses to utilize recycled materials (San Francisco Office of Economic and Workforce Development, n.d.).

3.2. Results and future goals

Purchasing in compliance with the Precautionary Procurement Ordinance has increased significantly, from \$1.5 million in 2008 to \$5.75 million in 2010, despite shrinking budgets (City and County of San Francisco, n.d.). The SFDE updates the list of approved products every three years. Over time, the SFDE has expanded its interpretation of the scope of the ordinance from toxics to the life-cycle implications of all City purchasing. The ordinance has been used as a model by several other governments in establishing similar programs, including the states of Hawaii and Washington, and the cities of Berkeley CA, Eugene OR, Portland OR, and Seattle WA (Said, 2011).

Forty-two percent of San Francisco's Green Certified Businesses report that business increased after certification (Said, 2011). Related to these efforts, in 2012 the City was recognized as the "Cleantech Capital of North America" in large part because of the amount of venture capital invested in clean companies in the greater metropolitan area (Figure 9), and the City's efforts to promote the industry (Business Wire, 2012). The city is now home to about 225 cleantech and green industry firms, and private developers have opened a cleantech incubation hub, in part with City financing (Said, 2011).

¹⁵ *San Francisco City Ordinance No. 21-06*. January 11, 2006. At http://www.sfenvironment.org/downloads/library/1_greenbusinessprogram.pdf

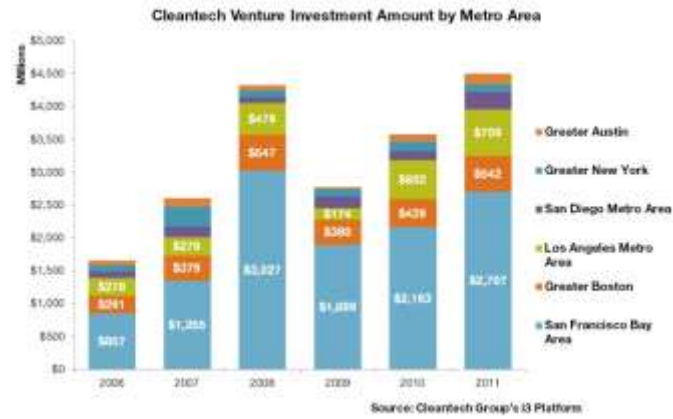


Figure 9. Cleantech Venture Investment Amount by Metro Area
Source: Business Wire, 2011.

4. Case Study 4: Portland OR: Integrating Bicycles into Every City Space

Portland ranked first in the 2008 SustainLane evaluation of the 50 largest U.S. cities (Karlenzig et al., 2007). This city of 550,000 residents is relatively small and not a national center of commerce, but it offers residents access to vast natural resources and environmental amenities, including some of the best air and water quality in the United States. In recent years, Portland's liberal culture and low property prices have attracted young people, creative professionals, and outdoor enthusiasts.

Portland's eco-city-like efforts have been primarily focused on limiting urban expansion and emphasizing realistic alternatives to cars for commuters. In 1979, state law mandated that the City establish an urban growth boundary and restrict development outside of city limits (EIU, 2011a). In 1993, the City adopted the United States' first city-level plan to reduce GHGs. Portland was also an early adopter of an aggressive green buildings policy in 2001 (updated in 2009) (Karlenzig et al., 2007). In 2009, the City merged its Bureaus of Planning and Sustainability, thereby "making 'sustainability the default of all policy, of all management, of all planning decisions'" (Scheffler, 2010). In addition to these programs, Portland is especially notable for a sixfold increase in bicycling since 1990, despite its low density (1,584 residents per km²), disadvantageous climate and topography, and high car ownership rates. The city has the highest bike commute rate in the U.S., nearly 6% (Pucher and Buehler, 2009).

4.1. Policy and measures

Although the percentage of bike commuters is increasing gradually in many U.S. cities (from 0.6% of all commuters in 1990 to 0.8% in 2009), Portland's rate of increase has far outpaced others as a result of a range of planning and promotional tools. In the words of a study recently commissioned by the U.S. Department of Transportation, "Portland is the American city that comes closest to implementing a truly comprehensive, well-integrated, long-term package of infrastructure, programs, and policies to promote cycling" (Pucher and Buehler, 2011).

Bike master plan: Portland first adopted a Bicycle Master Plan in 1995 (the plan was updated in 1998 and 2009) (Pucher and Buehler, 2011). The 1995 plan described an interconnected bicycle network that has been supported by several government programs to encourage biking. The 2009 plan has several key goals, the most important of which is that bicycling should be the most attractive transportation option for trips shorter than three miles, thereby assuring that 25% of all trips are made by bike (Geller and Borkowitz, 2011). The 2009 plan covers all city districts and includes different network expansion scenarios depending upon funding levels (OregonMetro.gov, n.d.). Figures 10 and 11 show the bike network's development trajectory.

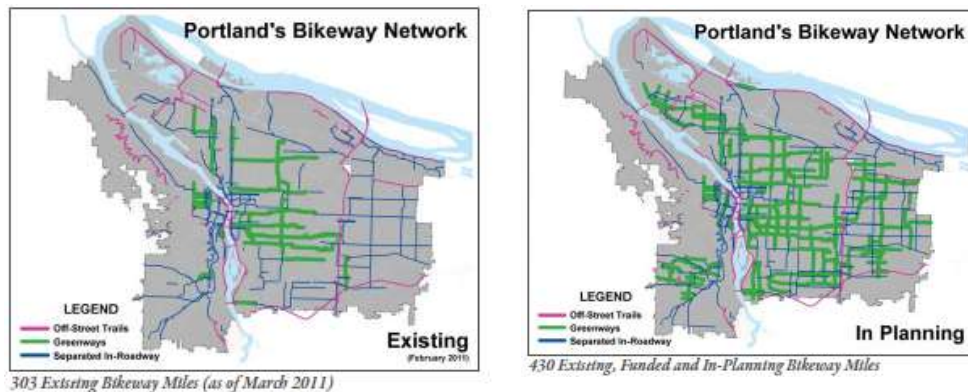


Figure 10. Portland's 2010 Bike Network Figure 11. Portland's Expected 2030 Bike Network

Source: Portland Department of Transportation, 2009.

Bike parking: In 2004, the City began to install bike parking areas in retail neighborhoods, usually by eliminating street parking in the area. By 2010, 40 bike parking units had been installed (Meisel, 2010). Local businesses apply to have bike parking installed. Businesses have enthusiastically embraced the program and perceive it to be helping create business and improve access (Geller and Borkowitz, 2011).

Bike traffic safety: The City piloted a system of high-visibility of bike lane demarcation on high-traffic streets. After a year of testing, the effort was expanded to several more intersections. The City is also increasingly using bike-only traffic signals to regulate bike movement separate from that of other traffic (Geller and Borkowitz, 2011).

Bike-friendly public transportation: A metropolitan area planning board is responsible for regional public transit planning. This board has eliminated fees, permits, and restrictions that applied to taking bikes on public transit. Every train and bus has bike carriage facilities. Bike route planning has been fully integrated into public transit expansion, and transit centers are served by bikeways. Special attention is paid to bike access at transit centers far from the city center (Pucher and Buehler, 2009).

Bike promotion: A City-funded group called SmartTrips was started in 2003 to encourage residents to use alternatives to cars. The program offers events for new residents, maps and information, and individualized marketing to pre-targeted residents in some areas (Pedestrian and Bicycle Information Center, n.d.). Information packs include small incentives, like pedometers and coupon books for local businesses. The program is very popular with residents, and a consulting arm now assists employees in shifting to non-car options for commuting. The City also coordinates many biking events, such as voluntary car-free Sundays (Geller and Borkowitz, 2011).

Bike to school: The City is using federal funds to partner with public schools to ensure that all students have bike access. These programs have reportedly dramatically increased community involvement in City efforts (Geller and Borkowitz, 2011).

Bikes in codes: Since 1998, the Portland City Government has pursued a transit-oriented development program to encourage mixed-use developments, often including affordable housing, that are served by transit and bike routes. The City has used federal funds to buy land and re-sell it to developers at lower-than-market rates contingent upon transit-oriented-development commitments. The City is also reforming codes to ensure that multi-unit buildings provide more long-term bike parking.

4.2. Results and future plans

Although Portland has experienced rapid population and economic growth since the 1990s, in 2004 the city's GHG emissions were only slightly above 1990 levels and had fallen by 12.5% on a per-capita basis (ICLEI-Global, n.d.). Since 1990, bike commuting has doubled in the city, and the bike network expanded by 10% over the course of one year after the passage of the 2030 Bicycle Plan (Scheffler, 2010; Geller and Borkowitz, 2011). The number of students who use active transportation to get to school increased from 28% in 2008 to 39% in 2010, and a 2008 study found that 18% of residents used bikes as their primary or secondary mode for work trips (Pucher and Buehler, 2011). Despite increases in biking, traffic fatalities decreased three times faster than the state rate and six times faster than the national rate between 1999 and 2009. The SmartTrips program estimates that it has reduced drive-alone trips by 9% - 13% in areas targeted by the scheme, at a cost of about \$10 per area resident (Pedestrian and Bicycle Information Center, n.d.).

The most surprising benefits are economic. Businesses near bike corrals are seeing increases in customers using bikes, and most welcome the shift from car to bike parking. Furthermore, increasing bike ridership entails substantial infrastructure costs savings. The entire cost of Portland's bike network up to 2008 was equivalent to the cost of a single mile of urban freeway. By 2040, investments in bike infrastructure may result in a benefit-cost ratio for health care and fuel savings between 3.8 and 1.2 to 1, and an order of magnitude greater when the value of a statistical life is incorporated (Kost, 2011). The city is becoming a mecca for biking enthusiasts; bicycle companies are flocking to Portland, and in 2008 the bicycle industry contributed \$90 million annually to the local economy. This was a 28% increase in value between 2006 and 2008 (Alta Planning + Design, 2008). Efforts are likely to be redoubled when the 2030 Bike Plan becomes mandatory through incorporation into the 2013 Transportation System Plan (Geller and Borkowitz, 2011).

5. Case Study 5: Vancouver, B.C.: Density Planning

Vancouver is a relatively small city (population 580,000) and is the EIU's second-greenest city in North America as well as the world's third-most-livable city (EIU, 2011b; EIU, 2012). The city has reduced its GHG emissions by 6% below 1990 levels despite 27% population growth and an 18% increase in jobs (City of Vancouver, 2012). Per capita, the city emits about 4.2 tonnes CO₂, in large part because of low-carbon electricity sources (primarily hydropower) and minimal transportation use. Buildings and vehicles make up more than 90% of the city's GHG emissions (buildings account for 55%, and transportation accounts for 37%—see Figure 12) (City of Vancouver, 2012). The city already has the largest public transit network in North America, with 5.4 miles of public transit per square mile of city space. A large proportion of commuters—25%—get to work using non-car options (City of Vancouver, 2012). Population density is relatively high, at 13,100 people per square mile (or about 5,000 people per km², the highest density in Canada and near New York levels) (EIU, 2011a). A notable feature of the city is the lack of freeways; since the 1960s, no freeways have been built inside the central city.

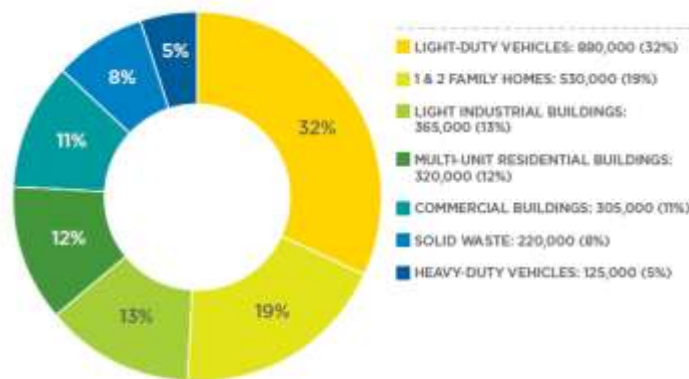


Figure 12. Vancouver's 2008 GHG Emissions Sources

Source: City of Vancouver, 2012

5.1. Policies and measures

Starting in 2008, the mayor assembled a cross-departmental team to construct a vision for making Vancouver the “World’s Greenest City” by 2020 (Vancouver Mayor’s Office, 2010). The plan establishes 10 long-term goals; density is a key to many, including that the majority of trips should be made by non-car modes, that every city resident should live within a five-minute walk from green spaces, and that the per-capita ecological footprint should be reduced by 33% (Vancouver Mayor’s Office, 2010). As a 2011 plan update states: “It is highly improbable, if not impossible, to achieve the targets in these categories without supportive land use decisions. Throughout the implementation of the Greenest City Action Plan, connections to land use decisions will continue to remain a key requirement for success” (Pitre-Hayes, 2011).

The city council unanimously adopted an EcoDensity Charter in 2008. The charter makes environmental sustainability a primary goal in all planning decisions, supported by secondary considerations of

affordability and economic growth. A guide was laid out to begin rezoning and implementing green building and density codes. City density can be a highly political subject in North America, and the City has made extensive efforts to communicate the benefits of density to residents at the neighborhood level.

Density Codes: Building code provisions have included: in 2004 the ability to build in-house apartments (called secondary suites), and in 2009 an allowance for additional, separate units, called laneway housing, to be built on low-density lots. Additional floor space was also allowed in 2009 for livable basements in single-family houses (Community Services Group, City Wide and Regional Planning, City of Vancouver, 2012). The 2009 changes allow for three households to occupy the same space that one would have occupied just 10 years ago while avoiding the dramatic aesthetic and character changes so often at issue in density debates. Both the 2030 plan and the Eco-Density Charter commit the City government to continuously reviewing existing building by-laws for new density opportunities.

Density Rezoning: Under the charter, rezoned new buildings must all meet LEED Gold with very high public transit density and use rates (EIU, 2011b). To increase incentives for higher density, the City is considering requiring developers to dedicate a percentage of developed land space to the City for parkland or other recreational purposes, to enable higher-density developments (Vancouver Mayor's Office, 2010). The City is also proactively looking into rezoning less-dense areas, especially around downtown.

Other Green Building Incentives: An experiment in developing a neighborhood-scale energy utility in part of the city has highlighted the economic opportunities for the deployment of such technologies (Pitre-Hayes, 2011). The City is now pairing density planning with development of fuel switching and energy conservation policies, targeting the development of district heating systems with neighborhood-scale operators to reduce construction costs and take advantage of economies of scale (City of Vancouver, 2012). The City plans on developing four new renewable energy systems for new, large, high-density developments within three years (Pitre-Hayes, 2011).

5.2. Results and future goals

The city's 500th laneway house was approved in early 2012 (Berg, 2012). Thirty-five percent of new houses now provide a secondary suite, up from 5% in 2000, and 88% of new single-family homes now include livable basements, up from 30% in 2000 (Community Services Group, City Wide and Regional Planning, City of Vancouver, 2012). Dense planning remains attractive despite fears of blight; the inner city's 2006–2011 population growth rate (11%) has been higher than the rest of the city's growth rate (4.4%) (Lazaruk, 2012). However, affordability is a growing problem. An unexpected consequence of higher-density limits has been real estate speculation, so housing prices in Vancouver are extremely high, rivaling those in extremely land-restricted places such as Hong Kong (Sinoski, 2012). The 2009 laneway and basement housing policies were in part aimed at solving this problem, and strong citizen pressure has forced the City to de-prioritize recent rezoning efforts that threatened to reduce low-income housing. The 2020 Plan aims for 33% percent reduction in GHG emissions by 2007; higher density is

considered a key strategy for achieving this goal (Vancouver Mayor's Office, 2010). In the meantime, the city is cautious about the air quality implications of higher-density developments, especially those located around arterial roadways. The metropolitan planning agency, Metro Vancouver, is helping the City prepare development guidelines to minimize air pollution impacts in such developments (Pitre-Hayes, 2011).

Appendix A: Examples of Design Principles for Eco- and Sustainable Cities

- Downton's (1993) Twelve Ecopolis Design Principles
 - Restore degraded land
 - Fit the bioregion
 - Halt urban sprawl
 - Optimize energy performance
 - Contribute to the economy
 - Provide health and security
 - Encourage community
 - Promote social equity
 - Respect history
 - Enrich the cultural landscape
 - Heal the biosphere
- Register's (2006) Most Important Eco-City Design Principles
 - Build the city like the living system it is: a three-dimensional, integral, complex model
 - Make the city's function fit with the patterns of evolution: i.e., regenerate natural systems, and support and express creativity and compassion
 - Start with land use patterns
 - Reverse the transportation hierarchy
 - Build soils and enhance biodiversity

Register also supports ecopolis principles (see above)
- Ten Melbourne Principles for Sustainable Cities (UNEP, 2002)
 - Provide a long-term vision for cities based on: sustainability; intergenerational, social, economic, and political equity; and individuality
 - Achieve long-term economic and social security: guarantee the right to potable water, clean air, food security, shelter, and safe sanitation
 - Recognize the intrinsic value of biodiversity and natural ecosystems and protect and restore them
 - Enable communities to measure and minimize their ecological footprint
 - Build on characteristics of ecosystems in the development and nurturing of healthy and sustainable cities
 - Recognize and build on the distinctive characteristics of cities, including their human and cultural values, history, and natural systems
 - Empower people and foster participation
 - Expand and enable cooperative networks to work toward a common, sustainable future
 - Promote sustainable production and consumption through appropriate use of environmentally sound technologies and effective demand management
 - Enable continual improvement based on accountability, transparency, and good governance.

- 10 Dimensions for Sustainable Cities (Kenworthy, 2006)
 - City has compact, mixed-use urban form; uses land efficiently; and protects the natural environment, biodiversity, and food-producing areas
 - Natural environment permeates the city's spaces and embraces the city while city and hinterlands provide majority of food
 - Road infrastructure is de-emphasized in favor of transit, walking, and cycling infrastructure, with emphasis on rail
 - Extensive use of environmental technologies for water, energy, and waste management – forming closed-loop systems
 - Central city and subsectors are human centers that emphasize access, circulate with non-car transport modes, and absorb high proportion of employment and residential growth
 - High-quality public realm expresses culture, community, equity, and good governance
 - Physical structure is highly legible, permeable, robust, visually appropriate
 - Economic performance is maximized through innovation, creativity, and uniqueness
 - Planning is undertaken through public debate, not predictive computer models alone
 - All decision making is sustainability based and integrates social, economic, environmental, and cultural considerations as well as compact, transit-oriented, urban form principles
- Van der Ryn's and Cowan's (1996) Ecological Design Process Principles
 - Solutions grow from a place
 - Ecological accounting informs design
 - Everyone is a designer
 - Nature should be made visible
- Van Dijk's (2010) 10 Indicators to Measure Urban Sustainability
 - Integrated water resource management: closing the water cycle, the link between water resources, the use of drinking water, and the eventual reuse of treated water
 - Energy management, reducing greenhouse gases
 - Waste minimization and integrated solid waste management
 - Different sanitation approach
 - Integrated transport policies
 - Pollution policies
 - Anticipation of climate change
 - Different housing policy
 - Objectives related to justice and equality
 - Integration in framework of urban management, while also managing urban risks
- Newman and Jennings (2009) Seven Elements of the Resilient City's Built Environment
 - Reliant on renewable energy
 - Carbon neutral
 - Made up of distributed infrastructure
 - Photosynthetic (food sustaining)

- Eco-efficient (waste reducing)
- Place-based (relevance to local culture)
- Served by sustainable transport
- Newman and Jennings (2009) Ten Strategic Steps Toward a Resilient City
 - Set the vision, prepare and implement strategy: guide through necessary changes, including infrastructure spending especially on transit for outer suburbs, new planning systems for restructuring the city to reduce vehicle miles traveled and overall energy consumption, new regulations for energy-efficient buildings and vehicles, and household-based awareness campaigns
 - Example: Brisbane, Australia's peak oil and climate change strategy, development task force
 - Learn on the job
 - Target public buildings, parking, and road structures as green icons
 - Build transit-oriented development, pedestrian-oriented developments, and green-oriented developments together
 - Transition to resilient infrastructure step by step
 - Use prices to drive changes whenever possible
 - Rethink rural regions with reduced oil dependence
 - Regenerate households and neighborhoods
 - Facilitate localism
 - Use approvals to regulate for the post-oil transition
- World Bank's Principles of Ecological and Economic Cities (Suzuki et al., 2010)
 - City-based approach, which allows local governments to lead a development process that takes into account their specific circumstances, including local ecology
 - Expanded and decision-making platform for collaborative design that accomplishes sustained synergy by coordinating and aligning the actions of key stakeholders (start with City assets first, then to City services and planning activities, and then to collaboration with other stakeholders)
 - One-system approach that enables cities to realize the benefits of integration by planning, designing, and managing the whole urban system and creating material and energy flows
 - Investment framework that values sustainability and resiliency by incorporating and accounting for life-cycle analysis, the value of all capital assets (manufactured, natural, human, and social), and a broader scope for risk assessment in decision making
- Roseland's Dimensions of the Eco-city (1997)
 - Revise land use priorities to create compact, diverse, green, and safe mixed-use communities around public transportation facilities
 - Revise transportation priorities to discourage driving and to emphasize "access by proximity"
 - Restore damaged urban environments
 - Create affordable, safe, convenient, and economically mixed housing

- Nurture social justice and create improved opportunities for the underprivileged
- Support local agriculture, urban greening, and community gardening
- Promote recycling and resource conservation while reducing pollution and hazardous wastes
- Support ecologically sound economic activity while discouraging pollution, waste, and the use and production of hazardous materials
- Promote simple lifestyles and discourage excessive consumption of material goods
- Increase public awareness of the local environment and bioregion through educational and outreach activities

REFERENCES

- ALMEC Corporation. 2011. "Study of Japanese experiences on sustainable urban development including pollution control and management, resource/energy efficiency and GHG reduction." Available at http://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1270074782769/6925944-1288991290394/Japanese_Experiences_Sustainable_Urban_Development.pdf.
- Alta Planning + Design. 2008. *The Value of Bicycle-Related Industry in Portland*. September. At <http://bikeportland.org/wp-content/uploads/2008/09/2008-portland-bicycle-related-economy-report.pdf>
- Alusi, A., R.G. Eccles, A.C Edmondson, T. Zuzul. 2011. "Sustainable Cities: Oxymoron or the Shape of the Future. " Harvard Business School Working Paper 11-062.
- Angel, S., S.C. Sheppard, D.L. Civco. 2005. "The dynamics of global urban expansion." Washington, D.C.: World Bank Transport and Urban Development Department.
- Australia Conservation Foundation (ACF). 2011. *Sustainable Cities Index: Ranking Australia's 20 Largest Cities in 2010*. Melbourne: Australia Conservation Foundation. Available at http://www.acfonline.org.au/uploads/res/2010_ACF_SCI_INDEX_REPORT.pdf.
- Department of Sustainability, Environment, Water, Population and Communities, Australia Government (DSEWPC). 2006. *State of the Environment 2006, Index of Indicators, Themes and Issues*. Available at <http://www.environment.gov.au/soe/2006/publications/drs/indicator/index.html>.
- Basiago, A.D. 1996. "The search for the sustainable city in 20th century urban planning." *The Environmentalist* 16: 135-155.
- Beatley, T. 2003. "Planning for Sustainability in European Cities: A Review of Practices in Leading Cities," in *The Sustainable Urban Development Reader*, S.M. Wheeler, T. Beatley, eds. New York: Routledge.
- Beatley, T., K. Manning. 1997. *The Ecology of Place: Planning for Environment, Economy, and Community* Washington, D.C.: Island Press.
- Berg, N. 2012. "Exit interview: Brent Tonderian, Vancouver's ousted planning director." *The Atlantic Cities*, Feb. 13. At <http://www.theatlanticcities.com/politics/2012/02/exit-interview-brent-tonderian-vancouvers-ousted-planning-director/1211/>
- Berrini, M., L. Bono. 2011. *Measuring Urban Sustainability: Analysis of the European Green Capital Award 2010 & 2011 Application Round*. European Green Capital Program Report. Available at

http://ec.europa.eu/environment/europeangreencapital/docs/cities/egc_analysis2010-2011.pdf.

Best, A., S. Giljum, C. Simmons, D. Blobel, K. Lewis, M. Hammer, S. Cavalieri, S. Lutter, C. McGuire. 2008. *Potential of the Ecological Footprint for Monitoring Environmental Impacts from Natural Resources Use: Analysis of the Potential of the Ecological Footprint and Related Assessment Tools for Use in the EU's Thematic Strategy on the Sustainable Use of Natural Resources*. Report to the European Commission, DG Environment. Available at http://ec.europa.eu/environment/natres/pdf/footprint_summary.pdf.

Betancourth, C. H. 2011. "Eco-infrastructures, feedback loop urbanisms and network of independent zero carbon settlements," in *Eco-city Planning: Policies, Practice and Design*, T. Wong and B. Yuen, eds. New York: Springer.

Birch, E.L., A. Lynch. 2011. "Measuring U.S. sustainable urban development" in *State of the World 2012: Moving Towards Sustainable Prosperity*. Washington, D.C.: World Watch Institute.

Boston Indicators Project. 2009. *A Great Reckoning: A Summary of the Boston Indicators Report 2009*. Boston: Boston Foundation. Available at http://www.bostonindicators.org/uploadedFiles/Indicators/Indicators2008/Homepage/Indicators_102309.pdf.

—. 2012. "Sustainable Development." <http://www.bostonindicators.org/Indicators2008/SectorCrosscuts/Default.aspx?id=10474>.

Business Wire. 2012. "Cleantech Group Recognizes San Francisco as 'Cleantech Capital of North America.'" March 27.

Calthorpe, P. 1993. *The Next American Metropolis: Ecology, Community and the American Dream*. New York: Princeton Architectural Press.

Calthorpe, P. 2011. *Urbanism in the Age of Climate Change*. Washington, D.C.: Island Press.

Campbell, S. 2003. "Green Cities, Growing Cities, or Just Cities? Urban Planning and the Contradictions of Sustainable Development," in *Readings in Planning Theory*, S. Campbell and S. Fainstein, eds. Oxford: Blackwell Publishing.

Canfield, C. 1994. "Cerro Gordo: prototype symbiotic community," presented at The Sustainability Project Conference, *Designing for Sustainable Communities*. Santa Barbara: American Institute of Architects, 7-10th April.

- Carruthers, J.I., G.F. Ulfarsson. 2003. "Urban sprawl and the cost of public services." *Environment and Planning B: Planning and Design* 2003, 30(4): 503-522.
- Carson, R. 1962. *Silent Spring*. Boston: Houghton Mifflin.
- Commission of the European Community (CEC). 1990. *Green Paper on the Urban Environment*. Brussels: European Commission.
- City of New York. 2011. *PlaNYC 2011, A Greener, Greater New York. Update April 2011*. Available at http://nytelecom.vo.llnwd.net/o15/agencies/planyc2030/pdf/planyc_2011_planyc_full_report.pdf.
- City of Stockholm Executive Office. 2007. *Stockholm Vision 2030: A Guide to the Future*.
- City of Vancouver. 2012. *Greenest City 2020 Action Plan*.
- City & County of San Francisco. no date (n.d.). "Step 9: Green Your Business." At <http://sfgsa.org/index.aspx?page=4590>.
- Community Services Group, City Wide and Regional Planning, City of Vancouver. 2012. *Monitoring Report: Basements in Single-Family Houses*. February. At <http://vancouver.ca/commsvcs/ecocity/pdf/12feb29BasementsMonitoringReport.pdf>.
- Corporate Knights of Canada. 2011. "The 2011 most sustainable cities in Canada." *Corporate Knights Magazine* 34. Available at <http://corporateknights.ca/report/2011-most-sustainable-cities-canada>.
- Dastur, A. 2005. *How Should Planning Engage the Issue of Sustainable Development? The Case of Hammarby Sjostad, Stockholm*. New York: Colombia University.
- Davis, D., A. Krupnick, G. Thurston. 2000. "The ancillary health benefits and costs of GHG mitigation: scope, scale and credibility," in *Ancillary Benefits and Costs of Greenhouse Gas Mitigation: Proceedings of an IPCC Co-Sponsored Workshop held on 27-29 March 2000 in Washington, D.C.*. Paris: OECD.
- Dawson. J 2006. *Ecovillages; New Frontiers for Sustainability*. White River Junction, Vermont, USA: Chelsea Green Publishing.
- Diamond, J. *Collapse: How Societies Choose to Fail or Succeed*. New York, N.Y, U.S.A.: Penguin Group. 2005.

- Doran, G. T. (1981). There's a SMART way to write management's goals and objectives. *Management Review* 70, 35-36.
- Ecocity Builders. 2010. "Ecocity definition." Available at <http://www.ecocitybuilders.org/why-ecocities/the-solution/ecocity-definition/>
- Economist Intelligence Unit (EIU). 2009. *European Green City Index: Assessing the Environmental Impact of Europe's Major Cities*. Munich: Siemens AG. Available at http://www.siemens.com/entry/cc/features/urbanization_development/all/en/pdf/report_en.pdf.
- . 2010. *Latin America Green City Index: Assessing the Environmental Performance of Latin America's Major Cities*. Munich: Siemens AG. Available at <http://www.siemens.com/press/pool/de/events/corporate/2010-11-lam/Study-Latin-American-Green-City-Index.pdf>.
- . 2011a. *U.S. and Canada Green City Index: Assessing the Environmental Performance of 27 Major U.S. and Canadian Cities*. Munich: Siemens AG. <http://www.siemens.com/press/pool/de/events/2011/corporate/2011-06-northamerican/northamerican-gci-report-e.pdf>.
- . 2011b. *Asian Green City Index: Assessing the Environmental Performance of Asia's Major Cities*. Munich: Siemens AG. Available at http://www.siemens.com/entry/cc/features/greencityindex_international/all/en/pdf/report_asia.pdf.
- . 2012. *A Summary of the Livability Ranking and Overview*. London: Economist Intelligence Unit. Available at http://www.eiu.com/Handlers/WhitepaperHandler.ashx?fi=Liveability_rankings_Promotional_August_2012.pdf&mode=wp&campaignid=Liveability2012
- Emerson, J., D. C. Esty, M.A. Levy, C.H. Kim, V. Mara, A. de Sherbinin, T. Srebotnjak. 2010. *2010 Environmental Performance Index*. New Haven: Yale Center for Environmental Law and Policy.
- Environmental Administration, City of Stockholm. 2009. *The City of Stockholm's Climate Initiatives*.
- Energy Sector Management Assistance Project (ESMAP). 2011. *Tool for Rapid Assessment of City Energy (TRACE): Helping Cities Use Energy Efficiently*. Available at <http://www.esmap.org/esmap/node/235>.
- Ericsson, K. 2009. "Introduction and development of the Swedish district heating systems: Critical factors and lessons learned." A report prepared as part of the IEE project "Policy development

- for improving RES-H/C penetration in European Member States (RES-H Policy)." At [http://www.res-h-policy.eu/downloads/Swedish_district_heating_case-study_\(D5\)_final.pdf](http://www.res-h-policy.eu/downloads/Swedish_district_heating_case-study_(D5)_final.pdf).
- Esty, D., C. Kim, J. Emerson, A. Hsu, M.A. Levy, A. de Sherbinin, V. Mara, J. Wang, D. Cong, Y. Cao, G. Cao, H.S. Chan, H. Shi., W. Li. 2011. *Towards a China Environmental Performance Index*. New Haven: Yale Center for Environmental Law and Policy. Available at <http://environment.yale.edu/envirocenter/files/China-EPI-Report.pdf>
- EU Green Capitals Program. 2010. *Stockholm: European Green Capital 2010*. Luxembourg: Publication Office of the European Union.
- EU Green Capitals Program. 2011. *Application form for the European Green Capital Award 2014*.
- Fan, C.C. 1999. "The vertical and horizontal expansion of China's city system." *Urban Geography* 20: 493-515.
- Fannie Mae Foundation. 2003. "Charrettes 101: Dynamic Planning for Community Change." *Building Blocks* 4(1): 1-11.
- Fellowship for Intentional Communities. 2012. "Ecovillage Director - List of Ecovillages." Available at <http://directory.ic.org/records/ecovillages.php>.
- Forum for the Future. 2010. *The Sustainable Cities Index 2010 - Ranking the 20 largest British Cities*. London, UK: Overseas House. Available at <http://www.forumforthefuture.org/project/sustainable-cities-index/overview>.
- Geller, R., T. Borkowitz. 2011. *Portland Bicycle Plan for 2030: One Year Progress Report*. April.
- Glaeser, E. 2007. "Great cities need great builders" *The New York Sun*, Jan. 19, 2007.
- Global City Indicators Facility (GCI). 2007 "Themes." Available at <http://www.cityindicators.org/themes.aspx>. Toronto, Ontario: University of Toronto.
- _____. 2008. *Global City Indicators Preliminary Report*. Washington, D.C.: World Bank. Available at http://www.cityindicators.org/Deliverables/Final%20Indicators%20Report%203_21_08_4-23-2008-924597.pdf
- Greater London Regional Planning Committee (GLRPC) 1929. *First Report*. London: Knapp, Drewett.
- _____. 1933. *Second Report (included Interim Report)*. London: Knapp, Drewett.

- Grossman, G., A. Krueger. 1995. "Economic growth and the environment." *Quarterly Journal of Economics* 110(2): 353-77.
- Hall, P., C. Ward. 1998. *Sociable Cities: the Legacy of Ebenezer Howard*. Chichester UK: John Wiley and Sons.
- Hall, P. *Cities of Tomorrow: An Intellectual History of Urban Planning and Design in the 20th Century* (3rd Ed.). Oxford: Blackwell Publishing.
- Hawken, P., A. Lovins, L.H. Lovins. 2000. *Natural Capitalism: Creating the Next Industrial Revolution*. New York: Little, Brown, and Company.
- Heine, W., A. Langworthy, N. McLean, J. Pyke, H. Raysmith, M. Salvaris. 2006. *Measuring Wellbeing, Engaging Communities: Developing a Community Indicators Framework for Victoria: The final report of the Victoria Indicators Project*. Melbourne, Victoria: Victoria University Institute of Community Engagement and Policy Alternatives (ICEPA).
- Hester, R. T. 2006. *Design for Ecological Democracy*. Cambridge MA: MIT Press.
- Holmgren, D. 2002. *Permaculture: Principles and Pathways Beyond Sustainability*. Hepburn, Victoria, Australia: Holmgren Design Services.
- Hoornweg, D., F.R. Nunez, M. Freire, N. Palugyai, M. Villaveces, E.W. Herrera. 2007. *City Indicators: Now to Nanjing*. Presented at the Third World Urban Forum, Vancouver, British Columbia, Canada, June 22, 2006.
- Hopkins, R. 2008. *The Transition Handbook: From Oil Dependency to Local Resilience*. White River Junction, Vermont, USA: Chelsea Green.
- Hough, M. 1984. *City Form and Natural Process: Towards a New Urban Vernacular*. New York: Van Nostrand Reinhold.
- Hough, M. 1992. *Out of Place: Restoring Identity to the Regional Landscape*. New Haven: Yale University Press.
- Howard, E. 1898. *Garden Cities of To-morrow*. London: S. Sonnenschein and Co., Ltd.
- ICLEI-Global, no date (n.d.). City of Portland, U.S.A. At <http://www.iclei.org/index.php?id=9330>.
- ICLEI-Local Governments for Sustainability USA (ICLEI USA). 2010. *The Process Behind PlaNYC: How the City of New York Developed its Comprehensive Long-term Sustainability Plan*.

- Innes, J.E. and D.E. Booher. 2000. "Indicators for sustainable communities: a strategy building on complexity theory and distributed intelligence." *Planning Theory and Practice* 1(2): 173-186.
- Intelligent Community Forum. 2009. "Stockholm, Sweden: Making 'Big' Work Better" Jan. 1. At <http://www.intelligentcommunity.org/index.php>
- Jacobs, J. 1961. *The Death and Life of Great American Cities*. New York: Random House.
- James, S., T. Lahti. 2004. *The Natural Step for Communities: How Cities and Towns can Change to Sustainable Practices*. Gabriola Island, B.C., Canada: New Society Publishers.
- Jenks, M., C. Jones. 2010. "Issues and concepts," in *Dimensions of the Sustainable City*, M. Jenks and C. Jones, eds. London: Springer.
- Joss, S. 2010. "Eco-cities – a global survey 2009." *WIT Transactions on Ecology and the Environment* 129: 239-250.
- Kahn, M. E. 2006. *Green Cities: Urban Growth and the Environment*. Washington, D.C.: Brookings Institute Press.
- Kamal-Chaoui, L., E. Leman, and R. Zhang, 2009. *Urban Trends and Policy in China*. OECD Regional Development Working Papers, OECD.
- Kappos, A.D., P. Bruckman, T. Eikmann, N. Englert, U. Heinrich, P. Hoppe, E. Koch, G.H. Krause, W.G. Kreyling, K. Rauchfuss, P. Rombout, V. Schulz-Klemp, W.R. Thiel, and H.E. Wichmann. 2004. "Health effects of particles in ambient air." *International Journal of Hygiene and Environmental Health* 207(4): 399-407.
- Karlenzig, W., F. Marquardt, P. White, R. Yaseen, R. Young. 2007. *The SustainLane U.S. City Ranking: How Green is your City?* Gabriola Island, B.C., Canada: New Society Publishers.
- Kennedy, C.A., J. Cuddihy, J. Engel Yan. 2007. "The changing metabolism of cities." *Journal of Industrial Ecology* (11), 43-59.
- Kennedy, C., S. Pincetl, P. Bunje. 2011. "The study of urban metabolism and its applications to urban planning and design." *Urban Pollution* 159: 1965-1973.
- Kenworthy, J. 2006. "The eco-city - ten key transport and planning dimensions for sustainable city development." *Environmental and Urbanization* 18(1): 67-85.
- Kost, R. 2011. "Portland Mayor Sam Adams says Portland's spent on its bike infrastructure what it would normally spend on a single mile of highway." *Politifact.com*, March 2. At

<http://www.politifact.com/oregon/statements/2011/mar/19/sam-adams/portland-mayor-sam-adams-says-portlands-spent-its-/>.

Lazaruk, S. 2012. "Downtown Vancouver's density highest in Canada." *The Province*, Feb. 9,. At <http://www.theprovince.com/business/Downtown+Vancouver+density+highest+Canada/6125342/story.html>

Levine, M., S. de la Rue du Can, N. Zheng, C. Williams, J. Amann, D. Staniaszek. 2012. *Building Energy Efficiency Best Policy and Policy Package Practice*. forthcoming.

Maclaren, V. 1996. "Urban sustainability reporting." *Journal of the American Planning Association* 62(2): 1-21.

McDonough, W., M. Braungart. 2002. *Cradle to Cradle: Remaking the Way We Make Things*. New York: North Point Press.

McDonough, W. 1992. *The Hannover Principles*. New York: William McDonough.

McHarg, I. L. 1969. *Design with Nature*. Wiley.

Meadows, D.H., D.L. Meadows, J. Randers, W. Behrens. 1972. *The Limits to Growth*. New York: Universe.

Meisel, D. 2010. "Bike corrals: local business impacts, benefits, and attitudes." At http://www.altaplanning.com/App_Content/files/PDX_Bike_Corral_Study_Meisel.pdf.

Moldan, B., A.L. Dahl. 2007. "Challenges to sustainability indicators," in *Sustainability Indicators: a Scientific Assessment*, T. Hak, B. Molden, A.L. Dahl, eds. Washington, D.C.: Island Press, pp. 5-24.

Mollison, B., D. Holmgren. 1978. *Permaculture One: A Perennial Agriculture System for Human Settlements*. Melbourne: Transworld.

MONET. 2009. *Cercle Indicateurs: Vue d'ensemble des indicateurs centraux - Relevé 2009*. Geneva, Switzerland: Switzerland Federal Office of Statistics.

Mumford, L. 1938. *The Culture of Cities*. New York: Harcourt Brace Jovanovich.

National Bureau of Statistics (NBS), 2011. *China Statistical Yearbook*. Beijing: China Statistical Press.

Newman, P., J. Kenworthy. 1989. *Cities and Automobile Dependence*. Brookfield, Vermont, USA: Gower Technical.

- Newman, P., J. Kenworthy. 1999. *Sustainability and Cities: Overcoming Automobile Dependence*. Washington D.C.: Island Press.
- Newman, P.W.G. 1999. "Sustainability and cities: extending the metabolism model." *Landscape and Urban Planning* 44: 219-226.
- Newman, P.W.G., R. Birrell, D. Holmes, C. Mathers, P. Newton, G. Oakley, A. O'Connor, B. Walker, A. Spessa, D. Tait. 1996. "Human settlements," in *Australian State of the Environment Report*. Canberra: Department of Environment, Sport and Territories. .
- Newman, P., T. Beatley, T., H. Boyer. 2009. *Resilient Cities: Responding to Peak Oil and Climate Change*. Washington D.C.: Island Press.
- Newman, P., I. Jennings. 2008. *Cities as Sustainable Ecosystems: Principles and Practices*. Washington D.C.: Island Press.
- Newsham, G.R., S. Mancini, B.J. Birt. 2009. "Do LEED-certified buildings save energy? Yes, but..." *Energy and Buildings* 41: 897-905.
- New York City. 2009. *Greener, Greater Buildings Plan*. At http://nytelecom.vo.llnwd.net/o15/agencies/planyc2030/pdf/greener_greater_buildings_final.pdf.
- New York City Department of City Planning. 2011. *Vision 2020: New York City Comprehensive Waterfront Plan*. At http://nytelecom.vo.llnwd.net/o15/agencies/planyc2030/pdf/vision2020_nyc_cwp.pdf
- Niemeijer, D., R. S. de Groot. 2008. "A conceptual framework for selecting environmental indicator sets." *Ecological Indicators* 8: 14-25.
- OregonMetro.gov. No date (n.d.). "Transit-Oriented Development." At <http://www.oregonmetro.gov/index.cfm/go/by.web/id/140>
- Organization for Economic Cooperation and Development (OECD). 2012. *Compact City Policies: A Comparative Assessment*. Paris, France: OECD.
- Oxford English Dictionary. No date (n.d.). Definition: "sustainable city." Accessed May 31, 2011. Available at: <http://oed.com/view/Entry/195210?redirectedFrom=sustainable%20city#eid19473149>
- Pedestrian and Bicycle Information Center. No date (n.d.). *PBIC Case Study – Portland, OR; Portland SmartTrips*. At <http://katana.hsrrc.unc.edu/cms/downloads/ENC.PortlandSmartTrips.pdf>.

- Pitre-Hayes, A. 2011. *Administration Report: Greenest City 2020 Action Plan (GCAP)*, VanRIMS No. 08-2000-20. July. At <http://vancouver.ca/ctyclerk/cclerk/20110712/documents/rr1.pdf>.
- Prasad, N., F. Renghieri, F. Shah, Z. Tohanis, E. Kessler, R. Sinha. 2009. *Climate Resilient Cities: A Primer on Reducing Vulnerabilities to Disasters*. Washington, D.C.: World Bank.
- PriceWaterhouseCooper. 2011. *Cities of Opportunity*. New York: PriceWaterhouseCooper..
- Pucher, J., R. Buehler. 2009. "Integrating bicycling and public transport in North America." *Journal of Public Transportation* 12(3).
- Pucher, J., R. Buehler. 2011. *Final Report: Analysis of Bicycling Trends and Policies in Large North American Cities: Lessons for New York*. March. New Brunswick, New Jersey, USA: Rutgers University.
- Real Estate Research Corporation. 1974. *The Costs of Sprawl: Environmental and Economic Costs of Alternative Residential Development Patterns at the Urban Fringe*. Washington D.C.: U.S. Government Printing Office.
- Register, R, 1987. *Eco-city Berkeley: Building Cities for a Healthy Future*, Berkeley CA: North Atlantic Books.
- Register, R. 2002. *Ecocities: Building Cities in Balance with Nature*. Berkeley CA: Berkeley Hills Books.
- Register, R. 2006. *Ecocities: Rebuilding Cities in Balance with Nature*. New Gabriola, B.C., Canada: New Society Publishers.
- Rickard, L., J. Jesinghaus, C. Amann, G. Glaser, S. Hall, M. Cheatle, A.A. Le Kama, E. Lippert, J. McGlade, K. Ruffing, E. Zaccai. 2007. "Ensuring policy relevance," in *Sustainability Indicators: a Scientific Assessment*, T. Hak, B. Molden, A.L. Dahl, eds. Washington, D.C.: Island Press, pp. 65-82.
- Roseland, M. 1997. "Dimensions of the eco-city." *Cities* 14(4): 197-202.
- Said, C. 2011. "Clean-tech 'accelerator' Greenstart opens in S.F." *San Francisco Chronicle*, Sept. 21. Available at <http://www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2011/09/21/BULQ1L6NT6.DTL>
- San Francisco Commission on the Environment. 2006. *San Francisco Precautionary Principle Ordinance Three-Year Report*. At <http://www.icss2012.net/files/2011/08/pp3yearreport.pdf>
- San Francisco Office of Economic and Workforce Development. No date (n.d.). "Stock based compensation payroll tax exclusion." At http://www.oewd.org/Stock_Payroll_Tax_Exclusion.aspx.

- San Francisco Planning + Urban Research Association. 2008. *Building San Francisco's Cleantech Economy: Analysis and Strategy Options*. Available at http://www.spur.org/documents/SPURCleantechReport_Sept2008.pdf
- Scerri, A., P. James. 2010. "Accounting for sustainability: combining qualitative and quantitative research in developing 'indicators' of sustainability." *International Journal of Social Research Methodology* 13(1): 41-53.
- Scheffler, D. 2010. "Case Study: City of Portland," in *Sustainable Cities: A Collection of Case Studies*. Committee on the Environment American Institute of Architects, San Diego Chapter. January.
- Shen, L., J.J. Ochoa, M.N. Shah, X. Zhang, X. 2011. "The application of urban sustainability indicators: a comparison between various practices." *Habitat International* 35: 17-29.
- Sinoski, K. 2012. "Is laneway housing an affordable housing solution?" *Vancouver Sun*. Feb. 10.
- Spirn, A. W. 1985. *The Granite Garden: Urban Nature and Human Design*. New York: Basic Books.
- Stockholm Executive Office. 2011. *Vision Stockholm Royal Seaport*.
- Stockholm City Planning Administration. 2010. *The Walkable City: Stockholm City Plan*.
- Stone, B. Jr., M.O. Rodgers. 2001. "Urban form and thermal efficiency." *Journal of the American Planning Association* 67(2): 186-198.
- Sustainable Seattle. 1993. *Sustainable Seattle Indicators of Sustainable Community: A Report to Citizens on Long Term Trends in Their Community*. Seattle WA: Sustainable Seattle.
- Sustainable Seattle. No date (n.d.). "All Indicators." http://www.b-sustainable.org/indicator_index. Seattle: Sustainable Seattle.
- Suzuki, H., A. Dastur, S. Moffatt, N. Yabuki, H. Maruyama. 2010. *Eco2 Cities: Ecological Cities as Economic Cities*. Washington D.C.: World Bank.
- Tanguay, G.A.; J. Rajaonson, J. Lefebvre, P. Lanoie. 2009. "Measuring the Sustainability of cities: an analysis of the use of local indicators." *Ecological Indicators* 10 : 407-418.
- Transportation Research Board and National Research Council. 2002. *Costs of sprawl: 2000*. TCRP Report, No. 74, Washington, D.C.: National Academies Press.

“Trends and Indicators for Monitoring the EU Thematic Strategy on Sustainable Development of Urban Environment: Final Report Summary and Recommendations.” 2007. VTT Technical Research Center of Finland.

United Nations Environment Programme (UNEP). 1990. *Human Development Report 1990*. Oxford: Oxford University Press.

_____. 2002. *Melbourne Principles for Sustainable Cities*. Nairobi: United Nations Environment Program.

United Nations. 1992. *Earth Summit Agenda 21: the United Nations Programme of Action from Rio*. New York: United Nations Press.

_____. 2012. *World Urbanization Prospects, the 2011 Revision*. New York: United Nations Press.

United States Environmental Protection Agency (U.S. EPA). 2003. *EPA’s Smart Growth Index in 20 Pilot Communities: Using GID Sketch Modeling to Advance Smart Growth*. EPA 231-R-03-001. Washington D.C.: Environmental Protection Agency.

United States National Resources Committee. 1935. *Regional Factors in National Planning and Development*. Washington, D.C.: U.S. Government Printing Office.

United States National Resources Planning Board. 1937. *Our Cities: Their Role in the National Economy*. Washington, D.C.: Government Printing Office.

Van der Ryn, S., S. Cowan. 1996. *Ecological Design*. Washington D.C.: Island Press.

Van Der Ryn, S., P. Calthorpe. 2008. *Sustainable Communities: A New Design Synthesis for Cities, Suburbs and Towns*. Gabriola Island, B.C., Canada: New Catalyst Books.

Van Dijk, P. 2011. “Three ecological cities: examples of different approaches in Asia and Europe,” in *Eco-city Planning: Policies, Practice and Design*, T. Wong, B. Yuen, eds. New York: Springer.

Van Dijk, P. 2010. “Beijing and Rotterdam eco-cities? Using 100 criteria for a classification of ecological cities.” Paper presented at the Knowledge Collaboration & Learning for Sustainable Innovation ERSCP-EMSU conference, Delft, the Netherlands, October 25-29.

Vancouver Mayor’s Office. 2010. *Vancouver 2020 A Bright Green Future: an Action Plan for Becoming the World’s Greenest City by 2020*. At <http://vancouver.ca/greenestcity/PDF/Vancouver2020-ABrightGreenFuture.pdf>.

Wackernagel, M., W. Rees. 1996. *Our Ecological Footprint: Reducing Human Impact on the Earth*. Gabriola Island B.C., Canada: New Society Publishers.

- "What are 'Eco-villages?'" 2008. *Scientific American*, Dec. 22. Available at <http://www.scientificamerican.com/article.cfm?id=what-are-eco-villages>.
- Wheeler, S.M., Beatley, T. 2004. *The Sustainable Urban Development Reader*. New York: Routledge.
- Wilson, E.O. 1988. *Biodiversity*. Washington, D.C.: National Academy Press.
- Wolman, A. 1965. "The metabolism of cities." *Scientific American* 213: 179-190.
- Woodlaw, L., K. Loewen. 2012. "The jury is still out on sustainability plans." *Proceedings of the American Council for an Energy Efficient Economy Summer Study*. Available at <http://www.aceee.org/files/proceedings/2012/data/papers/0193-000352.pdf>.
- World Commission on Environment and Development. 1987. *Our Common Future (Annex to document A/42/427 - Development and International Co-operation: Environment)*. New York: United Nations.
- Xiao, G., L. Xue, J. Woetzel, 2010. *The Urban Sustainability Index: a new tool for measuring China's cities*. Beijing: the Urban China Initiative.
- Zaman, A. U., S. Lehmann. 2011. "What is the 'Zero Waste City' Concept?" University of Southern Australia: Zero Waste SA Research Centre for Sustainable Design and Behavior.
- Zhou, N., L. Price, S. Ohshita, and N. Zheng. 2012. *A Guidebook for Low-carbon Development at the Local Level*. Berkeley, CA: Lawrence Berkeley National Laboratory. LBNL-5370E.